AD716790

MINUTES
OF THE TWELFTH
EXPLOSIVES SAFETY SEMINAR

SHERATON-PEABODY HOTEL

MEMPHIS, TENNESSEE 25-27 AUGUST 1970

Conducted by
ARMED SERVICES EXPLOSIVES SAFETY BOARD
Washington, D.C. 20314

562

MINUTES

OF THE TWELFTH

EXPLOSIVES SAFETY SEMINAR

SHERATON-PEABODY HOTEL

MEMPHIS, TENNESSEE

25-27 August 1970

Conducted by

ARMED SERVICES EXPLOSIVES SAFETY BOARD

Washington, D. C. 20314

TABLE OF CONTENTS

AUTHOR INDEX

SOURCE INDEX

WELCOMING ADDRESS

Colonel William Cameron III, USAF
Chairman
Armed Services Explosives Safety Board

Good afternoon ladies and gentlemen. Welcome to the Twelfth Annual Explosives Safety Seminar. It is good to see so many old friends and familiar faces.

As many of you know, the Armed Services Explosives Safety Board was established by an Act of Congress in 1928 after a disastrous accidental explosion at the Naval Ammunition Depot, Lake Denmark, New Jersey. The Board presently functions under a charter signed by the Secretary of Defense. One of the duties assigned the Board by this charter, and I quote, is to "provide impartial and objective advice to the Secretary of Defense and the Secretaries of the Military Departments on ammunition and explosives manufacturing, testing, handling, transportation, storage, and siting with special attention to preventing conditions that will endanger life and property within and outside DOD installations" end of quote.

In 1958 the Board Members discussed the many new problems associated with the manufacture of solid propellants for rocket motors. It was at that time that this Safety Seminar was conceived. The basic idea was to discuss explosives safety problems and exchange ideas on possible solutions which would improve safety. These seminars have continued annually with this the twelfth. For the common good, we have gathered together to study and improve explosives safety. Therefore, our motto for this year's seminar is "Explosives Safety - Government/industry Team Effort." We share many mutual problems and it is imperative that we, both Government and private industry, work together as a team with a single goal - to reduce explosives accidents to an absolute minimum.

The Board stands ready and willing to assist in this team effort when and wherever possible. Through this effort we are carrying out our first responsibility - preventing conditions that will endanger life and property.

Each year we find ourselves faced with new and different problems associated with explosives and ammunition. We hope that through the free exchange of ideas during this seminar, the solutions to these problems will be found or at least that this exchange will form the basis for further thought and study, new approaches or methods developed to eliminate possible hazardous situations.

In accordance with our Charter, the Board is comprised of three senior military officers, one from each Military Department, and a Chairman.

Each Military Department also has an alternate Board Member. The Chairman and the Board have a full-time Secretariat who support the Board in its activities. The Secretariat consists of two military officers and ten civilian engineers.

Our Civil Engineer Consultant is Mr. George Wigger, Office, Chief of Engineers, Department of the Army. Our legal advisor is Mr. Robert McKay of the Army General Counsel's Office.

This year we are honored to have with us representatives from several countries: Norway, France, Australia, Brazil, and Canada.

All of us deal with many types and kinds of ammunition and explosives; fortunately, few of us are closely associated with a major accident. I have a film which I would like to use to set the tone for our Seminar.

This accident occurred at Ammunition Supply Point One, Da Nang, Republic of Vietnam on 27 April 1969. This supply point was designed for the safe storage of approximately 25,000 short tons of ammunition but a waiver to store 50,000 short tons had been issued due to combat needs. At the time of the accident about 39,000 short tons of ammunition were stored. This ASP was comprised of both USAF and Marine Corps portions which are contiguous but have entirely separate identities.

In one corner of the ASP an area had been designated for the storage of retrograde ammunition. It was in this vicinity that a fire started. The fire quickly spread into the ASP despite attempts by 30-40 men using field firefighting equipment and later a 400-gallon pumper. The first munitions items involved in the fire were retrograde 3.5" white phosphorus rockets in wooden boxes, also parachute flares. These items eventually exploded spreading fire throughout both the Marine Corps and Air Force areas. In all, about 39,000 short tons of ammunition were lost, approximately $106,000,000 lost in this accident. Fortunately, casualties were minimal, two people killed and 78 injured. These numbers would have been much greater had it not been for the sound judgment and prompt actions initiated by responsible persons.

Film

Gentlemen, this is our business - and exactly what we are trying to prevent.

I sincerely hope that everyone will enjoy this seminar.

"MUNITIONS SAFETY IN THE

AGE OF DISSENT -

A PRIVATE CITIZEN'S VIEWPOINT"

By

J. E. SETTLES

A Private Citizen

It is a very personal and sincere pleasure to have an opportunity to attend this Twelfth Annual Explosives Safety Seminar of the Armed Services Explosives Safety Board. I was unable to attend the very first seminar 12 years ago. I did participate in Seminars No. 2, No. 3, No. 4, No. 5, No. 6, No. 7, and No. 8. More diverse responsibilities prevented me from attending the last three. It is a very real pleasure to be back with you.

As your program indicates, the subject of this discussion will be "Munitions Safety in the Age of Dissent." There is not an individual in this audience who is unaware of the upsurge of unrest in our society today. You may be conscious of this unrest only as a sort of nagging worry or uneasiness in the back of your mind. It may not be visibly evident that this social unrest could affect you to an extent beyond mental uneasiness.

It is a confusing situation. What is going on? Why is it happening? What's back of it all? What is going to happen in the future? What is the potential for this unrest to affect you and your life beyond just mental worry?

I am not going to insult your intelligence by telling you I have the answer to all of these questions. I do not have the "all-seeing" eye. I am going to give you one person's viewpoint about a portion of this unrest.

It is just barely possible this upsurge of unrest could have been predicted. Consider it from this viewpoint:

Our solar system functions in cycles. The earth rotates in cycles. With such majestic influence it should not be surprising if human behavior is a cyclic consideration. If such reasoning has any validity, then the

portion of this cyclic human behavior which affects safety will be the subject of this discussion.

Most of you are familiar with a cyclic phenomenon of human behavior that is associated with industrial lost-time injuries. A specific example: At the plant where I work we just can't get past the mark of twelve and one-half million accident-free man-hours despite our most intensive efforts. Time after time, as we have approached this plant all-time record, we have launched special safety campaigns, increased our safety publicity, planned special safety meetings, and a lot of other things. To date, there has always been another lost-time accident.

The reason: A cyclic phenomenon of human behavior. The day after a manufacturing plant experiences a spectacular lost-time injury will probably be the safest day of operations which the plant will experience. Everyone knows about the accident, they are talking about it, they are saying, "Gosh, why did that happen?" Everyone is unusually careful.

However, as the shock wears off, as things quiet down, normal routines - including mental habits - are reestablished. A euphoria takes over which is associated with the "it can't happen to me" attitude. This gradual mental relaxation, accompanied by increased carelessness, is an imperceptible and insidious thing. It continues to worsen until the next lost-time accident becomes inevitable.

There is another cyclic aspect of human behavior that is - right now - a very serious problem to all of us who are concerned about munitions safety. It is a potentially serious problem to you, personally, regardless of whether

your interest in munitions safety is manufacturing, transportation, research, administration, or whatever.

This cyclic "thing" about which we must become concerned is a social evolvement that is both nation-wide and world-wide in scope. An accurate description of this social cycle would be to call it "The Age of the Dissenter." A more charitable viewpoint might label the participants in this movement simply "objectors." They are described by emotional individuals as "radicals."

It is obvious that "dissenters," "objectors," and "radicals" are with us at all time. The greater scope and intensity of present-day activities justify calling the movement a social cycle.

And I believe it is a cycle. There is an "ebb and flow" to this sort of social emotionalism. A well known time in American history that saw dissenter activity at a peak was marked by the Boston Tea Party. That "age of dissent" culminated in the American Revolution. England found at that time that when dissenter activity is improperly handled it can have tremendous social repercussions.

Some may consider it an "alarmist" viewpoint to compare todays dissenter activities with the Boston Tea Party and the American Revolution. Consider these factors:

1. The popularity of "dissent" in our society today.
2. The unnatural influence of the vociferous minorities (and there are many of them.)
3. The sensitivity of members of Congress to these pressure groups.

4. The proliferation of the "Ralph Nadar" types on the national scene.
5. The obvious intoxication of young people as they take their first sip of social power in such activities as Nadar's Raiders and such radical organizations as the SDS, the Weathermen, and others.

The relationship between these social problems and munitions safety is not an obscure consideration. To get the connection, it is only necessary to remember that accidents involving explosives, munitions, and other dangerous materials are frequently spectacular. They get the headlines. The descriptive reports of these accidents by the news media, both written and oral, are always couched in lurid terms. The mitigating circumstances are seldom mentioned.

The news media, the dissenters, the radical groups in our society avidly seize upon the details of these unplanned events. With such details even the most languid dissenter organization can, overnight, become a vigorous, fire-breathing, self-righteous minority group which can cause very large waves on the ocean of public opinion and large repercussions in the Halls of Congress.

Think a moment. You are here today as a result of society's reaction to a spectacular accident involving munitions and explosives. It was the violent public and congressional reaction to the Lake Denmark explosion a number of years ago which resulted in the Armed Services Explosives Safety Board being authorized. Had ASESB never been authorized, there obviously would be no annual seminar and you would not be here today.

That action which resulted from those reactions years ago was well justified. Some of the actions which are being proposed in response to the social agitation in this "age of dissent" are not well justified.

I want to emphasize two aspects of the problem. One is the publicity aspect. The other is the legislative aspect. I will discuss the publicity aspect first.

In May of this year that general circulation magazine which claims a larger reader acceptance than any other American publication carried an article on transportation accidents involving explosives and other dangerous materials. The article did not cite the qualifications of the author or his background and I, personally, never heard of him.

I do know he picked up one accident that occurred 11 years ago and represented it as a recent occurrence. This author attributed all of his conclusions to a U. S. Senate Subcommittee that is investigating the problem. The Senators were represented as originators of a 5-point congressional program that would seem to give the Department of Transportation major additional authority in the field of munitions safety.

Recently, in discussing the article with a member of the Department of Transportation, it was made very clear to me that the actual details of the proposed congressional program are not intended to --- and actually do not --- encroach upon any other Governmental agency's area of vested interest. I was very glad to get that information.

However, with that clarification in mind, the article is an example of how distortions can be injected into reports by the news media. From that

viewpoint, it is worthwhile looking at the five points proposed in the program. I have a comment about each point.

Point No. 1 - "Empower the Secretary of Transportation to set safety regulations for all railroad operations, tracks and roadbeds, as well as for hazardous materials."

My comment: Notice that those words from the magazine article do not restrict the safety regulations to hazardous materials during transportation.

Point No. 2 - "That a super-agency be set up in the Department of Transportation with power to fix safety standards for the transportation of all hazardous materials and their shipping containers."

My comment: There is no distortion here. This is a legitimate function of the Department of Transportation. Agent George's tariff, and a number of similar documents, already provide a tremendously voluminous base upon which the super-agency could build. It is a tremendously complicated subject.

Point No. 3 - "That the Department of Transportation establish a board of top men in science and transportation to undertake a thorough review and updating of all hazardous materials standards and regulations."

My comment: The review and updating would be very good. It apparently was a distortion when they put in the phrase "ALL hazardous materials standards and regulations."

Point No. 4 - "That the Department of Transportation launch a concerted, systematic research drive into the cause and prevention of hazardous material accidents."

My comment: Research into the cause and prevention of hazardous material accidents during transportation would obviously be a legitimate function of the Department of Transportation. The magazine article did not use the phrase "during transportation."

Point No. 5 - "That a permanent joint congressional committee be set up to oversee the transportation of hazardous materials, and to inform the American people whenever anyone is taking unnecessary risks with their lives."

There is no distortion here, but I have this comment: Down through the years the "risk factor" in munitions safety has always been a point of big discussion. And the Senators should remember that it is certain the dissenter groups among the American people will always disagree with any congressional committee on interpretation of the phrase "unnecessary risk."

Now let me direct your attention to the legislative aspect for a few minutes.

For the last two or three years there have been versions of a Federal Safety Law pending in Congress. There have been many versions of this bill and a number of them would open the door for the Department of Labor to move into the field of munitions safety to an extent which would force one of two major eventualities.

The move to the Department of Labor would have to be either extremely effective or it - inevitably - would be extremely disruptive - disruptive to an extent that could seriously jeopardize those improvement goals which are the stated objective of the change.

It is to be noted the disruptive aspects overwhelmingly predominate in a proposed bill that will be debated in the House of Representatives, probably some time in September.

Any legislation which makes it possible for a manufacturing plant which is in full compliance with every written standard to still be penalized is certain to be wrong!

Any legislation that permits labor strikes with full pay for the strikers is certain to be wrong!

These are just t 'o of the more generalized disruptive potentials in the present legislative activities. I will comment on the disruptive potentials for munitions safety in just a moment.

The complexities and internal workings of the congressional legislative mills are great. The general public has little awareness of the ultimate possibilities until those "possibilities" suddenly become "realities." It is a point of considerable concern that if there is inadequate challenge of those undesirable portions of a bill, the unwise aspects, the potential for disruption of our economic and social balances, the unclear and controversial phrases may get included in the text which becomes law.

I would like it to be clearly understood that I have nothing against the Department of Labor, the Department of Transportation, the Interstate Commerce Commission, the Bureau of Explosives of the Association of American Railroads, the House of Representatives, the United States Senate, or any other organization that is trying to improve safety in the field of munitions and dangerous materials.

I have nothing against these groups. However, in order to be completely candid, I will admit that in the field of munition safety I am strongly biased in favor of the Armed Services Explosives Safety Board.

But regardless of the opinions, desires or politics of any individual, including myself, there are very important considerations that should influence conclusions and congressional action. One of these important considerations is a warning:

In matters involving munitions, explosives, and hazardous materials, the results can be disastrous if legislative action makes it possible for unknowledgeable people to superimpose their untrained judgment upon those decisions which are supported by years of exposure to such problems and judgment that has been tempered in the fires of personal experience.

There are no "ninety-day wonders" in the field of munitions safety.

Having a sign hanging across his chest with the word "Scientist" on it does not make a man an expert in the field of munitions safety. Don't misunderstand me. There are a number of respected and authoritative scientists in the field of munitions safety. But their stature is the result of years of experience, devoted study, and research.

Some universities now offer courses which lead to a degree in safety engineering. There is no college curriculum that can offer the experience of digging through the rubble of a hundred thousand pound detonation - or even a thousand pound detonation - to pin-point the reason the disastrous reaction occurred.

There is no college semester's work that can offer the shock of picking up broken human bodies, chunks of limbs, bones and brains.

I assure you that a graduate from the College of Bitter Experience will have far greater regard for the welfare of the American people than any dissenter organization can possibly feel. There are a number of individuals in this audience who appreciate - from their own experience - the point I am making.

The important point is this: All of those Governmental organizations I mentioned a few minutes ago that I am not mad at include on their staffs individuals who are expert in some phase of munitions safety. Any federal legislation which makes it impossible for that expert knowledge to be brought to bear upon our pressing problems is doing the nation a serious disservice. This is a vital consideration and it is true regardless of what organization the expert knowledge is now assigned to.

Another very important point of concern is "cost." And this is one context of the munitions safety problem in which the word "cost" does not refer to money considerations.

There are those "idealists" in this nation - particularly among the dissenter groups - who would achieve munition safety by going the abandonment route. It is their oversimplified point of view that there is no safety problem with munitions or explosives that do not exist. They would have us solve the problem by attempting to eliminate all munitions and hazardous materials. A corollary part of this idealistic philosophy is that aggressor nations no longer exist in this world. Realistically, we know that until human nature itself changes, there will be aggressor nations.

If this country's majority permits itself to be unduly influenced by these minority distortions, the ultimate "cost" is certain to be defeat of this nation by a well prepared aggressor. In this age of dissent the danger of that occurring is more real than many people imagine.

As I pointed out, in the 18th century the English underestimated dissenter influence in the American colonies. The American Revolution resulted and the strongest nation in the world evolved. A similar underestimate of dissenter influence in this 20th century could bring this same strongest nation back to its knees.

Some of you may have a detached feeling about all of this agitation and potential for change. You may be thinking, "My future is secure. Let them change. It won't affect me." And maybe you are right.

It probably would be an accurate assumption that the Department of Defense will always have responsibility for military airfield and cockpit safety, for shipboard safety, and for battlefield safety. However, a fair

percentage of people in this audience are employed in munitions manufacture, storage, transportation, research or related activities. These are the activities that are in the forefront of the discussions about change.

It should be expected that any "takeover" agency, with agitator proding and congressional backing, will be strongly motivated to demonstrate vigorous action. There will be much fanfare and publicity about the new organization; news releases and public statements will abound.

As a part of the fever, it should be expected that the "takeover" agency will add personnel "hand over fist" - and it is a point of serious concern that there are not that many safety men in this country who are really knowledgeable about munitions and hazardous materials. That point was proved during the build-up for the Vietnam conflict.

You should expect something like this to happen:

As a part of the takeover activity there probably will be a swarm of untrained, inexperienced "know-it-all" types who will descend upon us. Two-thirds of our time - yours and mine - will probably be spent generating official answers to unimportant questions. And in the meantime, those vital considerations which really prevent accidents will not receive the attention they should.

By its very nature, this meeting is strongly oriented toward technical matters. Most of us have felt the magnitude of our technical problems was so great and the need for solution to these problems so pressing that our social difficulties should be left to someone else. And a few years ago such an analysis of the problem was justified.

However, despite our desires, the present day situation shouts forth another admonition, particularly to those of us who are most likely to be affected. Let me put that admonition into words:

Get involved! If you have it within your capability to exert even a little influence at any point of decision, do it! Don't miss the opportunity!

HAZARDOUS MATERIAL IN TRANSIT -- WHY REGULATE?

William A. Brobst
Office of Hazardous Materials
Department of Transportation

You will notice that the title of my talk is itself a question. You know, many times it is easier to ask a question than it is to answer a question. I had a very inquisitive engineer working for me one time who had a bad habit of answering a question with another question. After listening to this type of repartee for a few weeks I finally asked him "Alan, how come you always answer a question with a question?" He replied, "Why not?"

We are in an era of asking questions. We ask questions now that we never would have asked twenty or thirty years ago. Our children are questioning us. We are questioning our parents and all of us are questioning our government. As Jim Settles pointed out in his keynote speech, we are living in an age of dissention. Now normally, when we think of dissention, we think of the hippie groups with their long dirty hair and their signs and their ragged clothes. But there are other dissenters as well. Senators Hatfield and McGovern are constantly questioning our involvement in the Vietnam War. Secretary Laird is questioning Congress on its less than overwhelming support for the ABM program. Ralph Nader is dissenting with regard to the attitude of industry and government on consumer affairs. The Department of Transportation is dissenting with regard to accident rates involving hazardous materials.

But things have become very complicated lately. Let's look at the recent phosgene shipments as an example of this growing complexity. Phosgene is a material which has moved in commerce in great bulk quantities for many years. The usual container for this material is a very heavy steel tank. Our regulations contain a number of provisions which these tanks must meet. Generally, the tanks are strong enough to withstand the type of serious transportation accident that you might expect to happen. But when we started talking about the shipment of the surplus <u>war gas</u> phosgene coming out of Colorado, suddenly the monster changed its color. Surplus war gas phosgene must be <u>much</u> a greater hazard than just plain old ordinary phosgene, and so the plain old ordinary safety precautions just didn't seem to be enough. Why? Because there was a serious concern that some of the activist dissention groups might try to blow up the trains or shoot holes in the tanks with high powered rifle bullets. Now the transportation safety standards were never set up to provide protection against <u>that kind</u> of accident. Even the railroad safety bill now under consideration by Congress does not contemplate Federal action to prevent that kind of

environmental stress. Well, this example was just to point out the confusion which we face in our governmental regulatory programs for transportation of hazardous materials.

The real question to look at this morning is "why should the Federal Government regulate the transportation of hazardous materials?" What good will come from regulation? Will the safety record be better? Why can't industry regulate itself? Why does the Government have to hold industry's hand? More basically, what is a regulation?

Webster's dictionary defines regulate to mean "to govern or direct according to rule; to bring under the control of law or constituted authority; to reduce to order, method, or uniformity; to fix or adjust the time, amount, degree, or rate of something." When we in the Office of Hazardous Materials talk about a regulation, we are talking about a rule or order, having the force of law, issued by an executive authority of the Government. That phrase, too, comes from Webster. In applying that phrase, we are looking primarily at incorporating some sort of safety standards into a regulation. A safety standard simplified, is merely the formalization of a level of performance. Webster says that a standard is "something established by authority, custom, or general consent; as a model or example; or as a rule for the measure of quantity, weight, extent, value, or quality." So the question of "why regulate" resolves itself into the following question: "Should the Government establish safety standards in the field of hazardous materials transportation?"

Yesterday your keynote speaker referred to the May 19, 1970, issue of the Readers Digest. On page 177 of that magazine you will find an article by Don Robinson entitled "Danger! Hazardous Materials in Transit." In that article Mr. Robinson has described a number of serious accidents involving hazardous materials, accidents that bordered on a catastrophe. That article explains in relatively clear, although somewhat emotional, tones, just exactly why the Federal Government needs to set safety standards in this area. It has become increasingly obvious that self-regulation by the industry is not going to be in the public interest. The public must therefore suffer for the convenience of the industry. Rather than go through all of the details here this morning I commend that article to your study and evaluation. The article is factual and I think, after reading it, you will agree that "<u>somebody</u> has to do <u>something</u>."

That somebody is a man named Smith. Admiral Willard J. Smith, former Commandant of the U. S. Coast Guard, has just been nominated by President Nixon to serve as the Department of Transportation's new Assistant Secretary for Safety and Consumer Affairs. This is a new secretarial position created by the President to provide a focal point for emphasis on the Department's safety programs for all modes of transportation. Although this is not the super-agency referred to in

the Readers Digest article, the appointment of Admiral Smith to this new post should certainly make it obvious to everyone that the Department of Transportation is going to move in the field of transportation safety.

One area of change in which you might all be interested is a new working relationship between the Office of Hazardous Materials of DOT and the Armed Services Explosives Safety Board of DOD. For a number of reasons, with which I will not bore you here, the DOD and DOT have not had a great deal of communication in the past in the area of transportation of explosives. We have had some communication involving military explosives or in resolving some particularly knotty questions that the Services themselves were unable to solve, but, other than that, our relationship was not particularly close. We are now looking at the results of an organizational study performed by the ASESB in which the study proposed a number of changes in the working relationship between the Office of Hazardous Materials and the ASESB. I am sometimes hesitant to use the "OHM" to describe our office since those letters also spell the word "ohm." Most of you know, I'm sure, that in the field of electricity, the ohm is the unit of resistance. Although we have sometimes been accused of fulfilling this role in the past, I assure you it is not our intention to function that way in the future. We expect to be working very closely with the ASESB in looking at hazard classification and testing for explosives and some of the other hazardous materials over which that Board has cognizance. The DOD has a great deal of experience in this area, experience which we can't afford to pass up. We believe that we can make use of this experience in directing us along the route of developing a cohesive and meaningful hazard classification system for explosives.

One question that keeps recurring when we talk about transportation safety is, "How much safety do we really get for the dollars we spend?" I am sure you all realize we can buy as much safety as we want to pay for. Absolute safety may be obtained but the cost is often prohibitive. For example, we can provide absolute safety in the transportation of 500 lb. bombs, by not allowing them to be shipped at all. This ought to reduce our accident rate to zero. But the cost would not be acceptable. The recent nerve gas shipments through the eastern states can give you an indication of how much it sometimes costs to provide an adequate level of safety. The real crux of the matter comes in determining how much safety is adequate safety. In the case of the nerve gas shipments, the Department of Defense and the public had quite different ideas of how much safety was adequate. Closing that gap cost the Department of Defense a great deal of money. Was it worth it? I don't know. No accidents happened, but then perhaps no accidents would have happened with much less safety as well. But those of you in the safety business know that it is very difficult to count the accidents that don't happen. You never really know just how safe you are until you start having accidents.

We in the Department of Transportation are willing to spend what funds we have in developing safety standards that are meaningful and practical. We can not afford to spend money unless some increase in safety will result. What we have to decide, then, is how much safety we are going to get for the dollars we spend. You know, "a dollar's worth of safety for a dollar spent." For that reason we plan to spend our dollars in the areas that seem to be causing us the most problems. Again, "the squeakiest wheel gets the grease." We really don't have much grease and we are surrounded with squeaky wheels, so we have to pick and choose in selecting which projects we are going to emphasize in order to obtain the most satisfactory ratio of cost-to-benefit.

At the present time, the Department is continuing its case-by-case evaluation and action program in the field of hazardous materials transportation safety. We have a tremendous backlog of regulatory proposals in this area. We are trying to handle that backlog and at the same time to develop the tools with which to set some meaningful safety standards. Each evaluation is carried out now using regulatory examples as a basis for comparison. But most of these examples were written by industry in years past, and reflect in many cases an economic bias rather than a safety bias.

Over the past few years, we have reached out on a spot basis to look underneath a few of the large boulders that exist in this aspect of the safety field. Under each one that we examined we found a very wormy situation indeed. Examples of these projects, which were initiated by our staff on a spare time basis, include pesticides leakage, stress corrosion of tank trailers, and piggy back transportation of tank trailers. Each time we turn over a stone we find a new batch of worms, worms which we didn't even know were there. Right now we don't have the capacity to turn over any more stones. For this reason, we need your help. We believe that it is wasteful of public dollars to keep this case-by-case function going, as well as being bad government. What we need is a cohesive system of safety performance standards. We can then evaluate the various situations against a standard rather than against some empirical examples. What kinds of things are we looking at here?

Until we define the various environmental stress factors which affect a package or vehicle containing hazardous materials, we can hardly be expected to set meaningful standards on the necessary degree of integrity of the packaging. We will either set standards which do <u>not</u> reflect an adequate degree of safety and which will result in losses due to injury or property damage, or we will set standards which are <u>too</u> stringent resulting in economic penalties due to high packaging and shipment costs. We have a responsibility to establish an appropriate level of safety for transportation of hazardous materials and we must make these standards meaningful.

The present hazard classification system is arbitrary. Perhaps that's being complimentary; it is also archaic. Instead of being based on

hazards in transportation, it is based upon laboratory hazards, physical form, or guess. Many of the classification categories are undefined except in generalities. For example, our regulations define a corrosive liquid as a liquid that is corrosive. They define a flammable solid as a solid that is flammable. They define Class A, B, and C explosives by examples rather than by standards. There are no benchmarks by which a member of the public can determine whether he is subject to Federal Law. Judgments as to whether the regulations apply are largely intuitive. We need a meaningful classification scheme to establish benchmarks for evaluation of hazards, distinguishing between different degrees and types of hazards, and providing for multiple hazards. Without such a system, materials such as chlorine, anhydrous ammonia, and hydrogen sulfide will continue to be transported without any indication to the public as to their toxicity. Liquids will continue to be defined as gases (such as phosgene and nerve agents). The hazards of transportation of cryogenic materials, and new unstable propellants, and materials subject to polymerization will continue to go unrecognized and uncontrolled by the Department.

The ultimate control in the transportation of hazardous materials is in the packaging. There are essentially no packaging standards at the present time. There are only a number of examples of packaging methods which have been memorialized in the regulations at the request of industry. Each segment of the affected industry developed its own packaging methods with no parallel development of a basic system for setting different levels of package integrity. The regulations continue to tell package manufacturers how many nails to use, how long the nails should be, and how far apart they should be. There is a dearth of information in the regulations on methods by which a manufacturer might test his package to determine its degree of integrity. At the present time, we do not even have information on all of the industrial testing methods used within the industry.

New packaging standards must be developed on an intermodal basis. The present engineering design specifications generally do not take into account air and water transportation at all. For example, tank trailer specifications were developed primarily upon the highway environment and never took into consideration the completely different dynamic loading picture encountered in rail transportation. Yet these trailers are now being transported piggy-back.

Transportation of pesticides is a good example of the consequences of our failure to have a meaningful packaging performance standard system. Because of the failure of industry to use packages with an adequate degree of integrity, the number of leakages of pesticides in transportation over the past two or three years has been astounding. The situation is so bad that the industry, all on its own, has set up full time decontamination teams to clean up these messes as they occur. As a Department, we have a responsibility here, but we can meet it only throug

better packaging standards. On the other hand, packaging of radioactive materials has required such a high level of package integrity that there has not been a single death or injury in 25 years of transportation of these materials. Somehow we must resolve these inequities.

We know that accidents happen; we occasionally hear about them; but we don't get any information on them. We are trying to set up an accident reporting system so that we can collect data on accidents. Without this data, we cannot predict the reaction of packages to an accident environment. We must have this data in order to prove out the theoretical standards which we are trying to develop. Many materials are so hazardous that even in the event of an accident we can not afford to allow them to be released. Yet how can we protect them against an accident if we don't know how to translate accident conditions into quantified benchmarks? Without the information on accidents we cannot correlate the two. As a result, we would continue to live with over-packaging and under-packaging. Both are extremely costly.

In trying to look at this kind of regulatory program, we must ask ourselves "how much safer will things really be if we make all of these changes?" How can we quantify the degree of safety in terms of injuries to people and losses to property? We all know that it is very difficult to try and project quantified changes in accident rates when we don't even have the base data on accident rates. We have no data collection system, and the industry figures are sparse, unrelated, and often unavailable. We have not had either the resources or the capacity in the past to attempt to generate this data on our own. This situation is changing, however, and we are beginning to collect data. We have seen the results of some of our actions in the reduction of accidents. The shipment of pesticides is a good example of this. We have taken some short term but positive actions to reduce the effect of leakage of pesticides. We have let the industry know that we are going to take further action with regard to packaging standards. One result of this minimum level study has been a reduction of the dollar loss from pesticide leakage during the last six to eight months.

When we are looking at a serious potential hazard such as the rail derailment problem, it is difficult to quantify the potential results of your regulatory action. Most derailments happen to have occurred in remote or rural areas. It might be that all future derailments will continue to occur in remote or rural areas regardless of any regulatory action we might take, but this seems hardly rational. To us it represents good fortune not good government. Yet because so few major derailments have actually occurred in the midst of densely populated areas, it will be difficult to significantly reduce the number of deaths in such instances. We can only hope that by establishing better safety standards, we might well prevent the catastrophe from happening. As I mentioned earlier, it is always difficult to count the accidents that don't happen.

One of the specific areas that we are going to look at involves the hazard classification system for explosives. As you probably know, a number of hazard classification systems are now in use. We prescribe one in our DOT Regulations. The Department of Defense has another system that they use for classifying explosives in TB-700-2. The United Nations has developed a different hazard classification system for explosives transportation. A lot of people complain about the shortcomings of our system. We complain about the shortcomings of the DOD system. But then both of those systems were devised for somewhat different purposes. Now we have the impact of the United Nations system to consider. We are going to have to make up our mind just which way we are going to go, and then put some effort into developing that system to make it what it needs to be. We are primarily concerned about the hazard of an item that is shipped. There are a lot of things that you can do to an explosive item in order to reduce the hazard during transportation. Perhaps our biggest difficulty here is one of semantics. What do we mean by classification system? Certainly we need some scheme to analyze the potential hazard of the raw ingredients of an item to be shipped. But perhaps that hazard is not the one that ought to be indicated by labels and markings on the outside of the package. We feel that the inherent hazard of the material should dictate the type of packaging and transportation control necessary to insure safety. The labels, placards, and other markings then should indicate the actual hazard to the public after those other controls have been imposed. So perhaps we are really talking about two classification systems, one to determine packaging requirements, one to determine labeling requirements. I think a lot of our difficulty in the past has arisen because we have tried to combine these two under the assumption that they were non-separable. We believe that they are separable and we intend to separate them. We have asked the ASESB to assist us in evaluating the propriety of the United Nations explosive classification system. A number of you are likely to become involved in this classification effort. We really need the benefit of your wisdom and experience in helping us to make some sense out of this presently very confused picture.

You may have seen a recent notice of proposed rule making which would convert our existing hazard labeling system over into the United Nations system. Under the U.N. scheme, labels would be required for packages of explosives. At the present time, most explosives are not required to have labels in transportation. Under the proposal, labels would be required. Some people have said "Well that's ridiculous to put a label on a bomb; it's obvious from looking at it what it is." But is it really so obvious? What is that bomb loaded with? Does it contain high explosives, incendiary materials, or is it inert? The hazard to the public is different in every case. We haven't absolutely made up our minds yet that bombs should be labeled, but these are some of the points we will have to consider. We are convinced, however, that we need the same labeling and identification system for military shipments that we use for civilian shipments. The firmen or policemen ought not to have to determine who sent the shipment before he determines what he has to do with it.

These are some of the problems that face us in carrying out our responsibilities to establish a meaningful safety standards program for transportation of hazardous materials. It seems clear to us that we have a responsibility to provide guidance to the public in this area. We want to provide this guidance in the form of clear and consistent safety standards. Under the present scheme of things, there seems no choice but to issue these standards as regulations having the force of law. Congress has directed us to do so. Experience directs us to do so, and conscience directs us to do so. By taking advantage of the best experience and the best expert advice that we can get, we are convinced that we can develop a regulatory program in this area that will provide a level of safety which the public has a right to expect of its government. Other branches of government are sometimes criticized by the public for not doing an adequate job in developing safety standards. We intend to do our job, and, with your help, we will.

RELATIVE EVALUATION OF PUBLIC HAZARD IN TRANSPORTATION

$$PHd = f\left(\frac{DH \cdot D \cdot Q \cdot ES \cdot TD \cdot PR \cdot BS}{Pk \cdot PO \cdot TC \cdot EA \cdot Id \cdot Cp}\right)$$

Phd: Degree of potential public hazard

DH : Inherent degree of potential hazard of lading

D : Dispersability of lading (gas > liquid > solid)

Q : Quantity of lading (weight, volume, pressure)

ES : Expected environmental stress

TD : Distance of transportation

PR : Potential adverse public or political relations

FS : Frequency of shipments

Pk : Degree of packaging integrity

PO : Packaging operations control

TC : Transport controls (speed, routing, sole use)

EA : Ease of emergency actions

Id : Ease of hazard identification

Cp : Degree of compliance with regulations

HOW TO RESOLVE UNRESOLVED EXPLOSIVES SAFETY PROBLEMS

Moderator:

K. S. Skaar
Naval Weapons Center
China Lake, California

How to Resolve Unresolved Explosives Safety Problems

by

K. S. Skaar
Safety Director
Naval Weapons Center
China Lake, California

Introduction:

The Naval Weapons Center has worked on a wide variety of development projects involving all types of explosive materials and ordnance items intended for Navy and Department of Defense use. These projects are managed by scientific and engineering personnel who must operate with a great amount of freedom to make decisions and judgments in order to encourage maximum use of creative innovations and solutions to problems. It has been found that it is very easy to arouse conflict between a safety staff and technical organizations whenever technical personnel are not convinced of the need to follow safety regulations that have been imposed by higher management levels.

The Safety Staff of the Naval Weapons Center has for a number of years been experimenting with various participative techniques for resolving safety problems of the Center with the objective of reducing conflict between technical and safety personnel. Usually consensus is reached on proposed actions, and a much higher commitment is obtained in carrying out solutions than is obtained with the nonparticipative processes. The people involved have been found to work together more harmoniously. While there are many possible variations of a basic technique, the purpose of this presentation is to show the audience a relatively simple discussion method that has proven successful as a staff training technique for reducing conflict and has also proven successful as a method for solving difficult problems encountered in the field.

Appendix A shows the five slides that constituted the outline followed in the seminar presentation at Memphis. This presentation was designed to acquaint the audience with a discussion method, which was thereafter to be used by the audience and the discussion leader.

The discussion method was demonstrated at the conference by selecting a problem suggested by the group at the first session and using the same problem in a modified form at the second session. However, time was not adequate to completely resolve either problem.

Some basic ground rules for the discussion were

1. Win/lose discussions should be minimized by not allowing anyone in the group to attack the ideas of another person in the group. (This may be difficult, but it is very important.)

2. The discussion leader must attempt to hear all suggestions and write down a very brief statement of each suggestion.

3. One of the most important functions of the discussion leader is to keep the discussion on the appropriate subject and to record all ideas, suggestions, problems, etc., pertaining to the particular phase of the discussion.

4. Evaluations of solutions to problems may be made when developing a definite course of action, but they should be discouraged prior to this time. If a person disagrees, he can propose the course of action that he thinks is most appropriate.

5. The discussion leader should not be too concerned about recording a certain amount of redundancy.

Appendix B summarizes the discussions on the two demonstration problems. Note that the two parts of the appendix are in outline form based on the outline given in the fifth slide shown in Appendix A. The intent of Appendix B is to demonstrate the kinds of communication generated, but it should be kept in mind that the process was not completed because of time limitations.

It can readily be seen that there may be more than one solution to the problems in Appendix B. For example, in an explosives-processing building used for full scale processing, a scientist might be required to wear the same basic protective equipment as an ordnance man. In the laboratory, however, a variety of solutions might be permitted as long as the requirements for the safety of personnel are met, especially if it can be determined that the rule in question was written for a production operation. Thus safety can be achieved, satisfying the safety man and the scientist without violation of Department of Defense or service directives.

Appendix A

Discussion Outline

NATURE OF PROBLEMS

- NONCOMPLIANCE WITH REGULATIONS
- ANIMOSITY BETWEEN LINE AND SAFETY
- BAD ATTITUDES
- LACK OF SUPPORT FROM MANAGEMENT
- BUCK PASSING

POSSIBLE REASONS FOR THE PROBLEMS

- MISUNDERSTANDING
- THE PRESSURE TO PRODUCE AND MEET DEADLINES
- NOT LIKING TO BE TOLD WHAT TO DO
- UNREASONABLE DEMANDS

THE NATURE OF PEOPLE

- WANT TO BE RESPECTED
- DON'T LIKE PERSONAL EVALUATIONS
- WANT TO ACHIEVE IF THERE IS AN INCENTIVE
- RESENTFUL OF CRITICISM
- DON'T LIKE TO CARRY OUT ARBITRARY DECISIONS MADE BY OTHERS
- MORE LIKELY TO SUPPORT THEIR OWN SOLUTIONS TO PROBLEMS
- LIKE TO PARTICIPATE IN DECISIONS
- LIKE TO HAVE ORGANIZATION SUCCESSFUL

AN APPROACH THAT HAS WORKED AT NWC

- IDENTIFY PROBLEMS
- GET LINE PEOPLE TO OFFER THEIR SOLUTIONS

A METHOD USED FOR TRAINING AND PROBLEM SOLVING

- STATEMENT OF GOAL OR PROBLEM

  WHAT DOES THIS MEAN?

- WHAT ARE THE OBSTACLES?

  TAKE ALL SUGGESTIONS

  MAKE CONDENSED LIST

- OBSTACLE #1

  WHAT DOES THIS MEAN?

  WHAT MIGHT BE DONE TO OVERCOME THIS OBSTACLE?

  ACTION WE CAN TAKE

  ASSIGNMENT OF RESPONSIBILITY, FOLLOW UP, COMPLETION DATE, ETC.

Appendix B

1. Problem discussed - 25 August 1970

   Getting Scientific Experts to Abide by Simple Safety Rules

2. Problem discussed - 26 August 1970

   A Scientific Expert Refuses to Wear Conductive Safety Shoes in Accordance with Plant Safety Rules

Twelfth Annual Explosives Safety Seminar
ASESB

Session A
25 August 1970

GETTING SCIENTIFIC EXPERTS TO ABIDE BY SIMPLE SAFETY RULES

1. He can jeopardize the safety of others and himself.

2. He may not have developed a need within himself for following rules.

3. You have to guard against your own envy of his expertise.

4. Proper ventilation is an example of a simple safety rule. Wearing protective devices is another example.

5. He must know what he is working with and what the potential is.

6. The expert has worked with this material 20 years and someone (safety people) want to improve his methods.

7. Anyone who has worked on something for 20 years has undoubtedly formed bad habits.

8. Instead of scientific expert we should use the term self-appointed expert.

WHAT DO WE SEE AS OBSTACLES IN THE WAY OF OVERCOMING THIS PROBLEM?

1. To convince the experts they have a problem.

2. To convince them the simple safety rules are going to solve the problems.

3. The expert is at a superior level in the management chain.

4. The safety expert has a selling job.

5. Defining the hazards.

6. There is a communication barrier.

7. The scientists fear of losing his creativity.

8. If you try to eliminate one obstacle, you may create one or more larger ones.

WHAT DO WE SEE AS OBSTACLES IN THE WAY OF OVERCOMING THIS PROBLEM? (Cont'd)

9. One of the obstacles may be money.

10. A 20-year accident-free record may be an obstacle.

11. The scientist might quit if you insist on the rule.

12. The difficulty of the scientist convincing the safety man.

Consolidated list of obstacles

1. People don't understand each others viewpoint - communication problem.

2. Do we have a problem?

3. Establishing the value and pertinence of the safety rule.

OBSTACLE NO. 1 - PEOPLE DON'T UNDERSTAND EACH OTHERS VIEWPOINTS - COMMUNICATION PROBLEM?

What does this mean to you?

1. The scientist doesn't understand the need for the Mickey Mouse rule.

2. There has to be an SOP.

3. The scientist doesn't realize he has to follow an SOP.

4. The scientist is dealing with technical data, and the safety man is dealing with regulations which may be incompatible.

5. The safety man may not understand the reason for the safety rule himself.

What might we do to overcome or resolve this obstacle?

1. Schedule a conference about 45 minutes before it is time to go home.

2. Compromise.

3. Identify the specific rule.

4. Have safety officer and scientist each explain what he is trying to do.

5. Make a solid determination of the importance of the safety rule.

What might we do to overcome or resolve this obstacle? (Cont'd)

6. Determine whether or not the man at the workbench can understand the regulation properly.

7. Explain the philosophy behind safety rules.

8. Have the scientist generate the data that supports his position.

9. Update the regulation.

Twelfth Annual Explosives Safety Seminar
ASESB

Session A
26 August 1970

A SCIENTIFIC EXPERT IN EXPLOSIVES REFUSES TO WEAR CONDUCTIVE SAFETY SHOES IN ACCORDANCE WITH PLANT SAFETY RULES. WHAT DO WE DO ABOUT THIS?

What does this mean to you?

1. Not enforcing a rule would be a breakdown in discipline.

2. I would like to know why he can't wear safety shoes.

3. One of the reasons for refusal was because safety shoes hurt his feet.

4. It is possible there is no technical reason for the shoes.

5. There is a question of whether he goes in other areas where shoes are needed.

6. Maybe the rule is not needed in this situation.

7. Could he jeopardize others by not wearing safety shoes?

8. A question: Do the rules apply to everyone alike?

9. The expert had worked with this material 20 years without an accident.

10. If there is a hazard, there might be alternate solutions.

WHAT OBSTACLES MIGHT WE ENCOUNTER IN SOLVING THIS PROBLEM?

1. His refusing to work.

2. Other employees might refuse to work.

3. If he does not wear safety shoes, shoes might start "hurting" other employees also.

4. The rules may have no meaning if not enforced in every case.

5. The safety officer may feel his power is undermined if he grants an exception.

6. His physical discomfort could have an adverse effect on his progress in his assignment.

WHAT OBSTACLES MIGHT WE ENCOUNTER IN SOLVING THIS PROBLEM? (Cont'd)

7. To deter his advancement of work might have a psychological effect.

8. The safety rule may be arbitrary.

9. The need for the rule for safety is questionable.

10. Scientific experts don't like to be told what to do.

11. There may be a disagreement regarding the real hazard.

12. The most practical answer may be too costly.

Condensed list of obstacles

1. The validity of the rule.

2. Possible disgruntlement of the employee.
3. The effect of noncompliance on others.

Discuss as part of Obstacle No. 4

4. The ultimate cost.

OBSTACLE NO. 1 - THE VALIDITY OF THE RULE

What does this mean to you?

1. Can you live with this regulation, or should it be eliminated or changed?

2. We need to know the basic reason behind the regulation.

3. We must recognize the unpredicability of explosives.

4. The rule may be too general.

5. Is compliance with this rule the only way to eliminate the hazard?

6. We may need to evaluate all our regulations concerning explosives.

7. Generally the rules are not written for laboratory situations.

What might we do to overcome this obstacle?

1. Give a new interpretation to this rule.

2. You can except a rule in a laboratory situation.

3. Buy custom made safety shoes that fit.

4. Use other means of grounding.

5. Have expert demonstrate and prove there is no hazard.

6. Get a third party to express his expert opinion.

7. Write new rules applicable to laboratories.

8. Let the laboratory group write its own rules.

OBSTACLE NO. 4 - THE ULTIMATE COST

What does this mean to you?

1. We can lose the whole plant if we don't enforce the rule.

2. We can lose an individual if we do enforce it.

3. We need to consider the cost of all alternatives.

4. We can lose the whole safety program if we don't enforce the rule.

5. The significance of the expert's work has a bearing on the solution.

6. It may influence whether or not we go on with the project.

What might we do?

1. Enforce the rule.

2. Make an exception to the rule.

3. #2 plus alternate means.

Session leaders note: One can readily see the possibility that the solutions that emerge at various activities could be quite different without violation of higher level regulations and directives. A solution at a given place would be dependent on the situations and management philosophies of the organization.

TRANSPORTATION OF HAZARDOUS MATERIAL

Moderator:

William A. Brobst
Office of Hazardous Materials
Department of Transportation

INTRODUCTORY REMARKS

William A. Brobst
Department of Transportation

As many of you know, the Department of Transportation is attempting to convert the existing detailed engineering design specifications in its regulations to a system of packaging performance standards. One of the primary benefits that we expect to see from this change is a more consistent approach to defining levels of safety for packaging of different hazardous materials, including explosives. We believe that the safety standards setting responsibility of the Federal Government are limited to telling the affected public what it expects of them in terms of ultimate performance and not how to do it. At the present time, we in DOT have had a great deal of difficulty in trying to equate the comparative levels of safety of different regulatory requirements in different proposals from the shippers or carriers. In order to be sure that one method is as safe as another, we must first define the various factors involved in both methods.

What we really have to try to determine is some accepted degree of potential public hazard. Once we have done this we can then use it as a basis for comparing other proposals or methods. We have had some rather severe problems in trying to establish a single acceptable level of potential public hazard because the public reacts to different types of hazards in different ways. The public tends to accept gasoline, for instance, as a common hazard about which they are not too concerned. On the other hand, they feel that nerve gas or phosgene present unacceptable levels of potential hazard. It is interesting to note that the transportation of gasoline by truck kills about 60 people a year, but the transportation of such allegedly horrible

things as nerve gas, phosgene, or radioactive materials has yet to claim its first death or injury victim in transportation. Now this is not quite true because there was one case where two workers had one of the heavy containers fall on them causing some broken bones!

In trying to determine what the potential public hazard is in a given transportation situation, we do have to consider many different things. In listing them we have gone through a pleasant little exercise in trying to express all of these different factors in a type of mathematical formula. We recognize the difficulties in trying to quantify the various factors in this formula, but it has been useful to us in reminding us of the various things to be considered in determining when a certain transportation situation will provide an adequate level of safety. For example, in some way, we have to consider the inherent degree of hazard of the material being transported, along with the form and quantity of that material. We must look at the different environmental stresses that shipments might be subjected to over some given distance and frequency of shipment. Public and political reactions must be considered. The integrity of the package, along with the degree of control in the packaging and transportation operations, can offset some of the disadvantages. The ease of emergency actions and the identification of the hazard will play an important part in determining the overall hazard to the public. Even the probable degree of compliance with the regulations must be looked at in some way. Because we have been unable to quantify these factors, we instead just point out that the potential public hazard is

function of many things. In mathematics the symbol "f" is used to signify the term "function." The following series of slides will show you how we examine these functions for all of the things discussed above. The last slide puts it all together.

RELATIVE EVALUATION OF PUBLIC
HAZARD IN TRANSPORTATION

Potential public hazard is a function of many things

PHd=f (many things)

$$PHd=f\ (DH)$$

Where DH=Inherent degree of potential
hazard of lading

HOW MEASURED

Flash Point
Degree of Toxicity
Explosive Limits in Air
Tendency Towards Hazardous Self-Polymerization
Ease of Detonation
Corrosion Rate
Radio Toxicity
Gas Density

$PHd = f\ (DH \cdot D)$

Where D=Dispersability of the Lading

GAS>LIQUID>SOLID>CAPSULE

$$PHd=f\ (DH \cdot D \cdot Q)$$

Where Q = Quality of Lading

1. Stored energy ---

   weight

   volume

   pressure)relates also to DH and to D)

2. Curies

3. Number of packages per vehicle

4. Bulk vs packaged

$$PHd=f(DH \cdot D \cdot Q \cdot ES)$$

Where ES -- Expected Environmental Stresses to be Imposed on the Package

- -

Heat
Cold
Vibration
Shock/Impact
Puncture
Moisture
Compression (Stacking)
Reduced Pressure

- -

Careful Handling
Rough Handling
Minor Mishaps
Serious Accidents
Maximum Credible Accidents

$$PHd=f(DH \cdot D \cdot Q \cdot ES \cdot TD)$$

Where TD= Distance of
Transportation

Short Trip vs Long Trip - Days
vs Weeks - Direct vs In-Transit
Storage

$$PHd=(DH \cdot D \cdot Q \cdot ES \cdot TD \cdot PR)$$

Where PR Degree of Adverse Public Relations or Political Factors

- Surplus War Gas - Phosgene
- Nerve Gas
- Munitions
- Anhydrous Ammonia - Crete, Nebraska
- Sabotage - Yippies and Peaceniks

PHd not necessarily actually increased, but has some effect -- original PHd no longer acceptable.

$$PHd=f(DH \cdot D \cdot Q \cdot ES \cdot TD \cdot PR \cdot FS)$$

Where FS = Frequency of Shipments

1000 shipments per year is greater potential hazard than 1 shipment per year, in terms of exposure to transportation risks.

$$PHd = f\left(\frac{DH \cdot D \cdot Q \cdot ES \cdot TD \cdot PR \cdot FS}{PK}\right)$$

Where PK = Degree of Packaging Integrity

- o Higher pressure rating
- o Thicker container walls
- o Stronger materials of construction
- o More corrosion-resistant materials
- o Greater impact resistance
- o Better welding techniques
- o Better pressure relief devices
- o Better quality control testing
- o Better maintenance and inspection of used packages

$$PHd = f\left(\frac{DH \cdot D \cdot Q \cdot ES \cdot TD \cdot PR \cdot FS}{PK \cdot PO}\right)$$

Where PO = Degree of Control in Packaging Operations

Cleaning containers before shipment

Attachment of seals and caps

Securing of locking rings

Replacement of gaskets

Removal of previous product

Right product in right can

Attachment of labels

$$PHd=f\left(\frac{DH\cdot D\cdot Q\cdot ES\cdot TD\cdot PR\cdot FS}{PK\cdot PO\cdot TC}\right)$$

Where TC = Degree of Transport Control

* Speed of vehicle

* Routing -
  High accident rate routes
  Population centers
  Traffic congestion

* Sole use of vehicle
  Escorts
  Comingling of packages
  Incompatibility of ladings

* Tie - down and stocking

* Application of placards

$$PHd = f\left(\frac{DH \cdot D \cdot Q \cdot ES \cdot TD \cdot PR \cdot FS}{PK \cdot PO \cdot TC \cdot EA}\right)$$

Where EA = Ease of Emergency Action

- Detection of Leakage -
  - Odor
  - Color
  - Physical appearance
  - Fuming nature
  - Pressure or weight loss
- Firefighting Requirements - Water vs Foam
  - Solubility in water
  - Water pollution
  - Dilution
- Likelihood of Explosion in Fire
- Are Emergency Action Instructions Provided?

$$PHd=f\left(\frac{DH \cdot D \cdot Q \cdot ES \cdot TD \cdot PR \cdot FS}{PK \cdot PO \cdot TC \cdot EA \cdot Id}\right)$$

Where ID = Ease of Identification

Do Labels identify hazard?

Do Placards Identify Hazard?

Is the Name of the Poison Included

in Papers or on Placards/Labels?

$$PHd=f\left(\frac{DH \cdot D \cdot Q \cdot ES \cdot TD \cdot PR \cdot FS}{PK \cdot PO \cdot TC \cdot EA \cdot ID \cdot Cp}\right)$$

Where Cp - Degree of Compliance With Regulations

- Classifications
- Packaging
- Loading
- Handling
- Identification
- Transportation
- Unloading

$$PHd = f\left(\frac{DH \cdot D \cdot Q \cdot ES \cdot TD \cdot PR \cdot FS}{PK \cdot PO \cdot TC \cdot EA \cdot ID \cdot Cp}\right)$$

PHd = Potential Public Hazard

- -

DH = Inherent Hazard of Lading

D = Dispersability of Lading

Q = Quantity of Lading

ES = Environmental Stresses

TD = Distance of Transportation

PR = Public/Political Reaction

FS = Frequency of Shipments

PK = Integrity of Packaging Operation

PO = Control of Packaging Operations

TC = Control of Transport Operations

EA = Ease of Emergency Actions

Id = Ease of Identification of Hazard

Cp = Compliance With Regulations

NEW APPLICATIONS OF AMMONIUM NITRATE
SLURRY EXPLOSIVES

Moderator:

Dr. W. E. McQuistion
Naval Ordnance Station
Indian Head, Md.

BLANK PAGE

New Applications of Ammonium Nitrate Explosives

W. E. McQuistion, Chairman
Naval Ordnance Station
Indian Head, Maryland

Ammonium nitrate-fuel oil mixtures and aqueous gelled slurry explosives have been used extensively in the mining industry. In these applications they are effective and inexpensive. The safety and convenience of mixing the components at the site of application are additional advantages of these explosives.

For various reasons ammonium nitrate explosives have been used to only a limited extent as military explosives. However, in recent years they have been undergoing evaluation for certain applications. Mr. Lippe D. Sadwin of the Naval Ordnance Laboratory, White Oak described experiments evaluating ammonium nitrate-fuel oil as an airblast source for nuclear blast simulation. Mr. Theodore J. Sullivan of the Naval Ordnance Station, Indian Head discussed part of the evaluation of ammonium nitrate gelled slurry explosives for possible use in munitions.

Following are abstracts from these presentations:

Ammonium Nitrate/Fuel Oil, (AN/FO), a Safer Airblast Source

by L. D. Sadwin
U. S. Naval Ordnance Laboratory

AN/FO is being developed as an airblast energy source for nuclear blast simulation. Results of recently completed blast measurements on AN/FO charges weighing up to 100 tons have been published in a technical report, NOLTR 70-32, "Blast characteristics of 20- and 100- Ton Hemispherical AN/FO Charges, NOL Data Report," 17 March 1970. These results indicate that the AN/FO blast performance closely approximates that of TNT. NOLTR 70-32 also contains thermal stability data on AN/FO which indicate no self-heating of the explosive in these large sizes.

The safety advantages of AN/FO over the use of TNT or other explosives used for large explosions are numerous. The ease of handling factor becomes quite significant when large explosions are contemplated. AN/FO explosive placement operations take about one fourth of the time required for a comparable size, cast block, TNT charge. Bulk handling systems developed by industry for AN/FO mixing and placement reduce the personnel requirement considerably. Thus, fewer men for a shorter time are exposed to the explosive hazard. Additionally, since the fuel oil is not mixed with the fertilizer grade ammonium nitrate until placement, the hazards during transport to the firing site are far less than for any other known explosive system. Further information on AN/FO charge preparation has been published in NOLTR 70-205, "AN/FO Charge Preparation for Large Scale Tests," 8 October 1970.

Characteristics of Aqueous Gelled Slurry Explosives

T. J. Sullivan
Naval Ordnance Station
Indian Head, Md.

As part of a program to evaluate alternate explosives for military ordnance, the stability and low temperature boostering of three types of ammonium nitrate gelled slurry explosives were examined:

(1) GSX Type I - Containing no metal fuels or condensed explosives (RDX, TNT)

(2) GSX Type II - Containing metal fuels but no condensed explosives

(3) GSX Type III - Containing both metal fuels and condensed explosives.

All GSX compositions examined were thermally unstable and changed composition, particularly water content, on storage Types I and II also exhibited mechanical instability with separation of liquid from the gel matrices. This was a source of difficulty in loading and storage of test containers, as the liquids tend to leak and contaminate magazine areas.

Sensitivity to initiation decreased with temperature for all types with Type I being the most difficult and Type III the least difficult to initiate.

PREFACE

Since the work reported herein was conducted by five discrete branches within the organizational structure of the Naval Ordnance Station at Indian Head, this report has been divided into five sections for clarity and ease of presentation.

Section 1, Volumetric Stability of Candidate Gelled Slurry Explosives, relates the work performed by Dr. Alan Roberts on the dilatometer tests and of Joseph Mastroianni on coefficients of cubical expansion.

Section 2, Thermal Stability of Candidate Gelled Slurry Explosives, is the result of work conducted by W. G. Gough, R. D. Barefoot, and C. L. Whitman of the Applied Science Department.

Section 3, Field Testing of Candidate Gelled Slurry Explosives, summarizes work done by J. S. Ervin and L. D. Korkia on low-temperature booster sensitivity.

Section 4, Analytical Method of Determining Gelled Slurry Explosives Compositions, presents procedures developed by Mrs. A. C. Richardson and Mrs. P. P. Wheeler.

Section 5, Loading Candidate Explosives Into Test Configurations, is devoted to the mixing of GSX Type III and PBXW-112 and the loading procedures used in preparing test samples for the other agencies involved in this program. This work was performed by L. D. Henderson and J. P. McDevitt in our Pilot Plant.

Overall program management was the responsibility of T. J. Sullivan, L. A. Dickinson, and W. E. McQuistion. Mr. W. F. Holden was responsible for coordinating the efforts of the different groups involved in this program.

ABSTRACT

The effort of Naval Ordnance Station, Indian Head, in relation to the Alternate Munitions Fill Program has been directed in the following major areas:

(1) Loading of candidate gelled slurry explosives (GSX) into appropriate test configurations for the many other agencies conducting tests in this program.

(2) Evaluation of the thermal and physical stability of the candidate GSX.

(3) Evaluation of low temperature boostering requirements of the candidate GSX in the Bomb Mk 82 Mod 1.

It has been found that all the GSX candidates are compositionally unstable particularly with regard to their water content. Types I and II also exhibit mechanical instability by the presence of liquid phases not retained in their gel matrices. This has been a source of great difficulty in loading test sample containers, particularly bombs, as the liquids tend to run out of the bombs and contaminate magazine areas. No difficulties of this nature were encountered with Type III.

It was found that the sensitivity to initiation decreased with temperature for all types and that GSX Type I was most difficult and GSX Type III least difficult to initiate.

CONTENTS

Page

FIGURES

TABLES

INTRODUCTION

The objective of the Alternate Munitions Fill Program has been the development of an alternate explosive fill for possible use in principal military ordnance items or the adaptation of available industrial explosives to that purpose.

Four candidates were originally suggested:

(1) Gelled Slurry Explosive (GSX) Type I, a GSX not containing metal fuels or condensed explosives in the form of RDX or TNT

(2) GSX Type II, a GSX containing metal fuels but not condensed explosives

(3) GSX Type III, a GSX containing both metal fuels and condensed explosives

(4) PBXW, a castable explosive developed by the Naval Ordnance Laboratory, White Oak.

The Naval Ordnance Station, Indian Head, was charged with the responsibilities of loading test-sample containers with candidate GSX for all participating laboratories in the Alternate Munitions Fill Program, evaluating the thermal and physical stability of the candidate GSX, and conducting booster-sensitivity tests at low temperatures.

This report describes the results of the effort of the Naval Ordnance Staion, Indian Head on this program.

Section 1

VOLUMETRIC STABILITY OF CANDIDATE GELLED SLURRY EXPLOSIVES (U)

1.1 INTRODUCTION.

In volume limited systems such as bombs, mines, and warheads, changes in volume of the explosive fill with temperature and/or age determine the magnitude of any internal pressure changes which could result in rupture of the case or exudation of material through ports. Two simple tests were carried out on candidate explosive fills to determine changes in volume with age at 125° F and changes in volume with temperature between the limits of –40° and 70° C. These tests are described and results and conclusions reported below.

1.2 DETERMINATION OF VOLUME CHANGES DURING LONG-TERM STORAGE AT ELEVATED TEMPERATURE.

Volumetric stability tests were carried out on samples of each candidate in accordance with the following test specification.

1.2.1 Test Specification.

Materials Required:

(1) Three 50-ml glass flasks, each with a neck ground to accept a glass fitting which includes a stopcock and a horizontal length of calibrated capillary tubing. The capillary tubing had a bore diameter as close to 2 millimeters as possible and a length of approximately 1 meter.

(2) Three clips for the ground glass joints.

(3) An oven with a mean temperature of 125° ± 1/2° F. Periodic temperature fluctuations up to ±5° F with a time period less than half an hour may be permitted.

(4) Foamed polystyrene blocks shaped to contain the glass flasks and surround them with a 4-inch-thick wall of the same materials.

(5) Silicone stopcock grease.

(6) Mercury.

(7) Three thermocouples connected to a suitable recording instrument.

Procedure:

Tests shall be carried out in triplicate on each candidate in the following manner:

Load the flasks with 50-ml of the candidate explosive; clean the ground portion of the flask necks and grease them with silicone grease. Then insert the stopcock and capillary fittings and clip them firmly into place. Place the flasks in the oven along with the foamed polystyrene containers. After 8 hours, place the flasks inside the foamed polystyrene containers and insert a thermocouple through each container wall so that it is in contact with the flask wall. The temperature recording instrument should indicate a constant 125° ± 1/2° F. Open the stopcocks and introduce a short bead of mercury into each capillary tube. Close the stopcocks and mark the positions of the surface of the mercury closest to the sample, ensuring that the capillary tubes are all horizontal. The distance travelled by the mercury beads should then be measured at weekly intervals.

The expansion rate of the material as indicated by the movement of the mercury bead should not exceed 2% in 90 days. Over the 90-day test period, fluctuations of volume resulting from changes in atmospheric pressure will be averaged out when plotting the results.

1.2.2 Results.

The results of the tests were averaged for each candidate and plotted (Figure 1). As Type III was developed only recently by Indian Head, results were only obtained over a period of 27 days so that the tests were not completed for this candidate. The GSX Type I (without aluminum) and GSX Type II (with aluminum) samples expanded an average of 2.4% and 1.8%, respectively, after 90 days at 125° F.

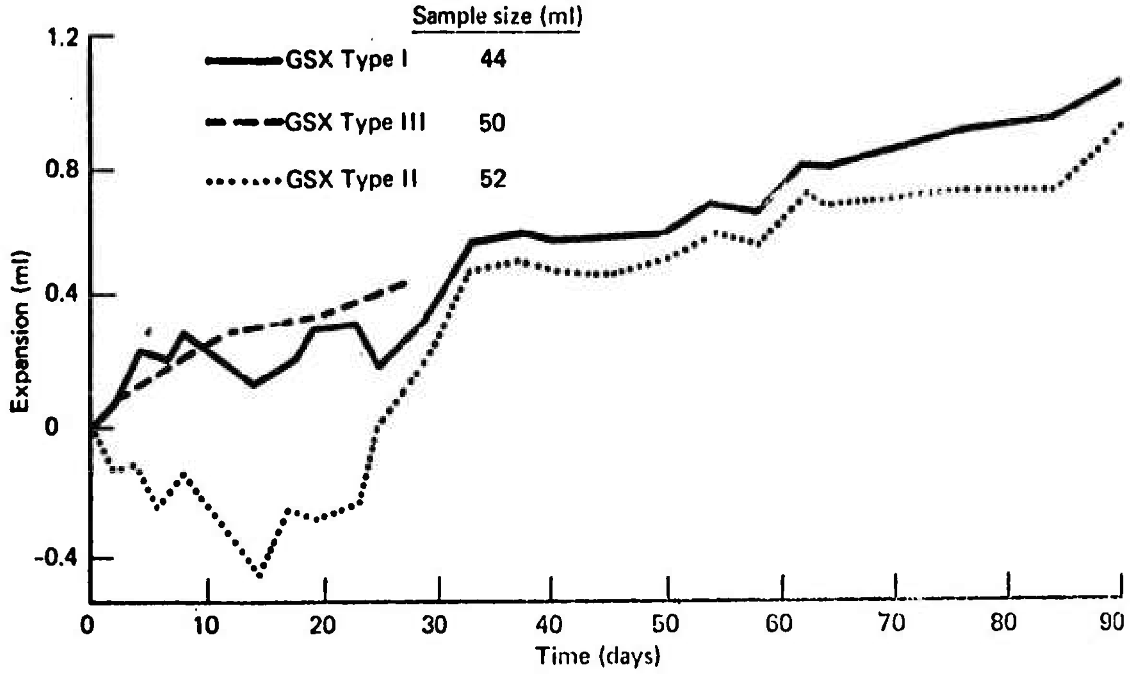


FIGURE 1. GSX VOLUMETRIC STABILITY TEST RESULTS

1.2.3 Discussion of Results.

Comparison of the results for individual test samples shows that the results are reproducible to within ±10%. Inspection of the samples at the end of the tests indicated no apparent change for Type II but showed that gas bubbles that were entrained in Type I migrated to the surface. Increases in the volume of

the contents of the test apparatus containing GSX Type I may result therefore from entrapped gas bubbles rising to the surface and bursting. The released gases would expand as they would have been at a slightly higher pressure in microscopic sized bubbles because of surface tension effects. Tests should be repeated on samples without entrained gas bubbles to eliminate this possible source of error.

1.3 DETERMINATION OF COEFFICIENT OF THERMAL EXPANSION.

1.3.1 Procedure.

The thermal volumetric expansion characteristics of samples of candidate GSX were determined using a dilatometric method.

A dilatometer consisting of a 25-ml round bottomed flask fitted with a calibrated and graduated capillary tube was filled with an accurately determined volume of silicone oil. The dilatometer was then immersed completely in a series of baths controlled to temperatures ranging from -40° to 70° C. The volume of the oil indicated by the level in the graduated tube was recorded at each bath temperature after the system had come to equilibrium. The procedure described above was then repeated with a weighed sample of a GSX candidate replacing a portion of the silicone oil. (The volume of the explosive sample was determined using previously derived density data for the materials.) As the whole test for each sample was conducted over a period of only 3 days, there was insufficient time for expansion produced by chemical reaction to become significant.

1.3.2 Results.

The results of the tests are plotted in Figure 2, silicone oil alone, Figure 3, silicone oil plus GSX Type I, Figure 4, silicone oil plus GSX Type II, and Figure 5, silicone oil plus GSX Type III. It was considered that the data could be represented by a linear function within the limits of experimental error. Thermal coefficients of cubical expansion calculated from the data shown in the figures are given below:

	Thermal Coefficient of Cubical Expansion Between -40° and -70° C (ml/ml-°C)
GSX Type I	7.1×10^{-4}
GSX Type II	12×10^{-4}
GSX Type III	8.4×10^{-4}
Typical high explosive	5×10^{-4}

1.3.3 Discussion of Results.

The calculations are quite straight forward and need not be reported in detail. The results are considered to be accurate to within ±3%, as determined by this procedure.

The explosive sample appeared to be unchanged when inspected at the completion of the tests but there may be some distribution of explosive in the oil or absorption of oil by the explosive.

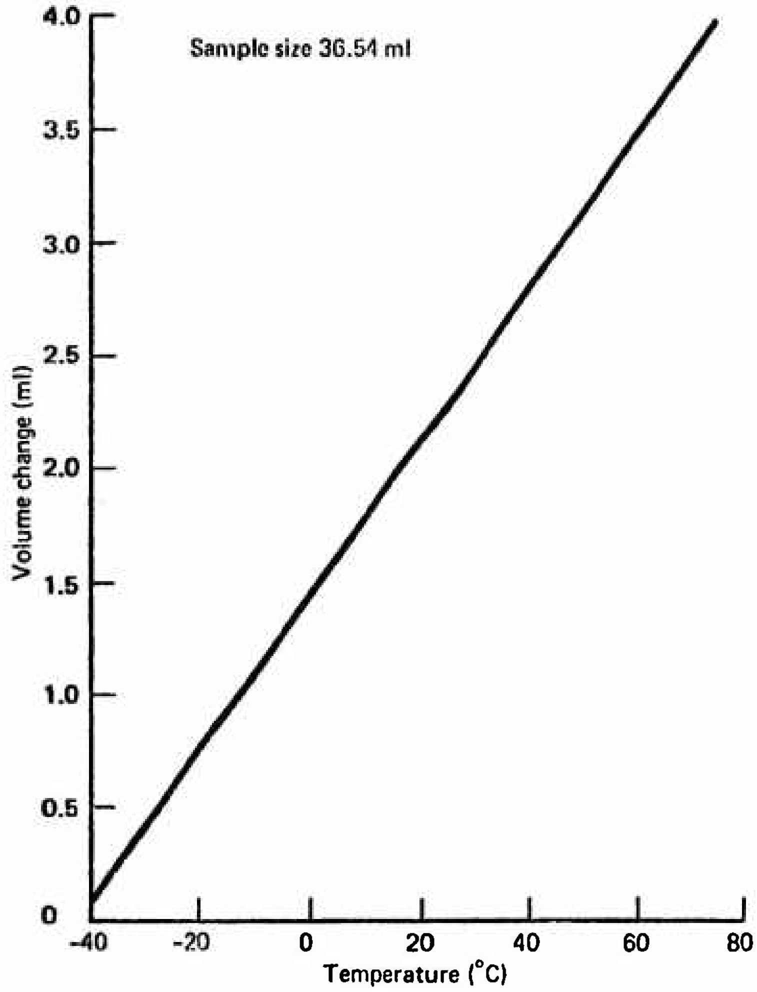


FIGURE 2. THERMAL EXPANSION TEST RESULTS OF SILICONE OIL

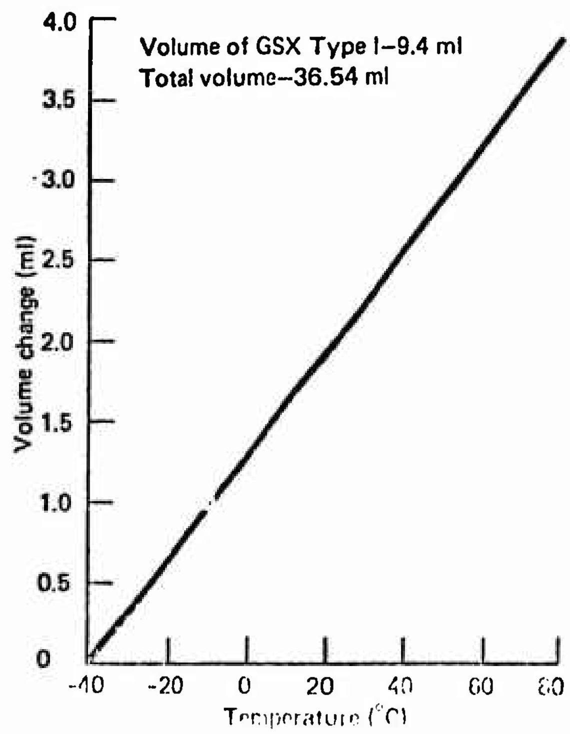


FIGURE 3. THERMAL EXPANSION TEST RESULTS OF SILICONE OIL PLUS GSX TYPE I

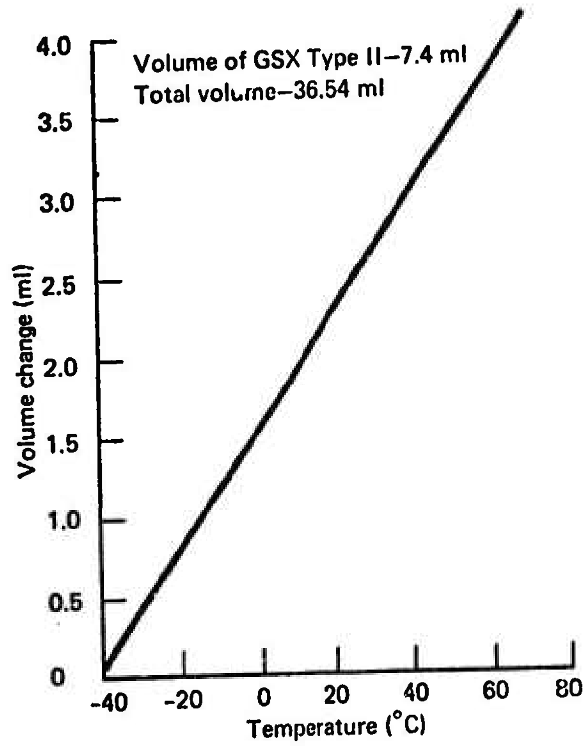


FIGURE 4. THERMAL EXPANSION TEST RESULTS OF SILICONE OIL PLUS GSX TYPE II

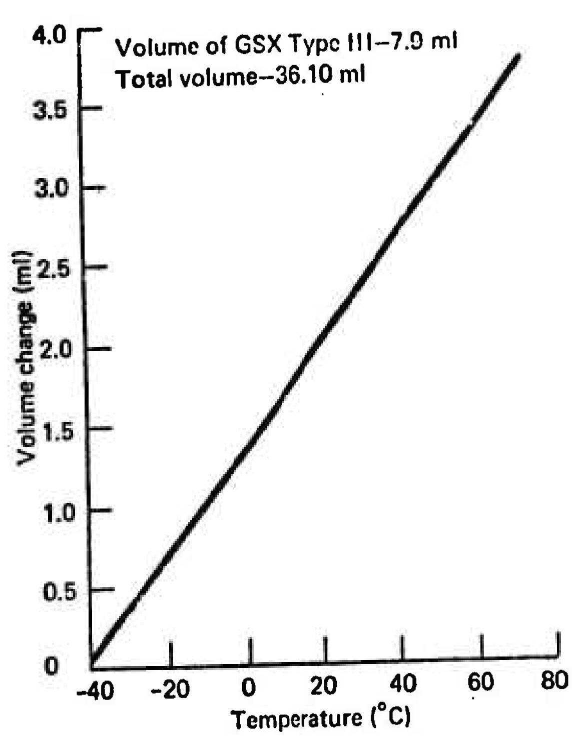


FIGURE 5. THERMAL EXPANSION TEST RESULTS OF SILICONE OIL PLUS GSX TYPE III

1.4 CONCLUSIONS AND RECOMMENDATIONS.

Both GSX Type I and GSX Type II were seen to expand in volume by about 2% over a period of 90 days when stored at a constant temperature of 125° F. Results were obtained for GSX Type III over a period of 27 days. However, over the period, the results appear to be very similar to those of GSX Type I.

Further tests should be carried out to check the reproducibility of the results, and tests should be carried out on degassed samples of GSX Type I for the reasons discussed in Section 2.2.3. Tests should also be carried out at other temperatures to determine the effect of temperature on the processes producing the observed volume changes.

The decrease in volume exhibited by GSX Type II over the first 20 to 30 days of the test has been observed with all samples tested and appears to be a real effect which may result from changes in the gel structure over this period.

The coefficients of volumetric expansion of GSX Types I, II, and III were found to be 7.1×10^{-4} 12×10^{-4} and 8.4×10^{-4} ml/ml-°C, respectively, between the limits of -40° and 70° C. These coefficients appear to vary very little, and no discontinuities were observed in the volume versus temperature data between the quoted temperature limits.

Further work needs to be done to determine the mutual solubilities of the explosive candidates and the liquid used in the dilatometer.

Section 2

THERMAL STABILITY OF CANDIDATE GELLED SLURRY EXPLOSIVES (U)

2.1 INTRODUCTION.

Explosive fills for ordnance items should be thermally stable for reasons of safety and weapons effectiveness. The following tests were made on all GSX candidates to assure that they would be both safe and effective after encountering elevated temperature and high humidity in an environment that might exist in the supply system:

(1) Differential thermal analysis
(2) Time-to-ignition at constant temperature
(3) Weight loss at constant temperature
(4) Hygroscopicity.

2.2 DIFFERENTIAL THERMAL ANALYSIS (DTA).

This test enables one to determine the temperature at which phase changes, reactions, or decomposition take place in the explosive.

2.2.1 Procedure.

A 2-gram sample of the explosive to be tested is placed in a glass test tube (15 X 125 mm). An equivalent amount of 120-micron glass beads is placed in another test tube. This is the thermally inert temperature reference. Iron versus constantan thermocouples, enclosed in very-thin-wall glass capillaries, are immersed in the test and reference samples. They are held in proper position by Teflon spacers and tape. The two test tubes are then placed in a large aluminum heat sink. This in turn is placed in a temperature-programmed oven.

After connecting the thermocouples to a suitable recording device, the oven is closed and the heating rate set, usually 1° C per minute. Data are plotted as thermograms in which the temperature of the reference sample is the abscissa and the difference in temperature between the test and reference sample is the ordinate.

2.2.2 Results.

The DTA results are shown in Figures 6 through 8.

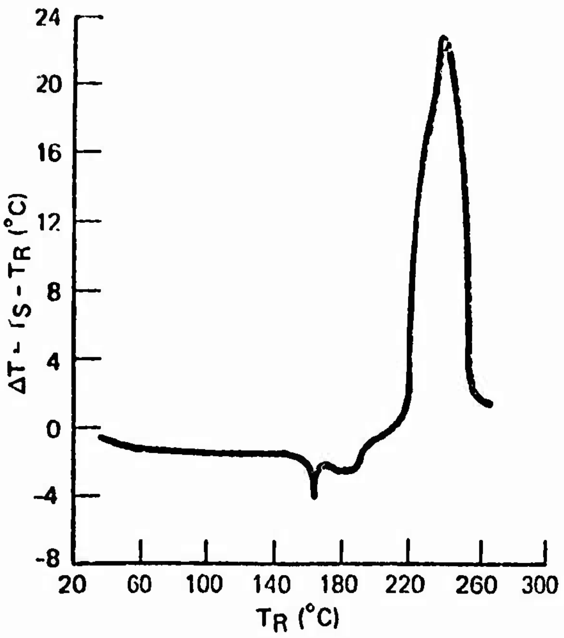


FIGURE 6. DTA RESULTS OF 3 GRAMS OF GSX TYPE I

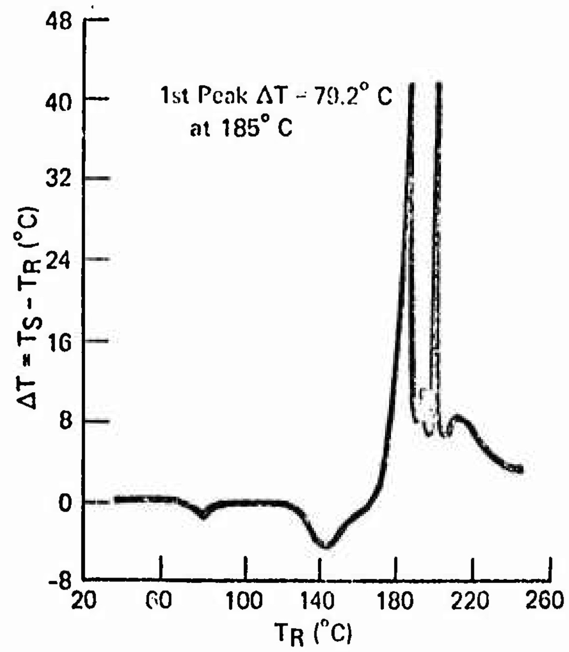


FIGURE 7. DTA RESULTS OF 3 GRAMS OF GSX TYPE III

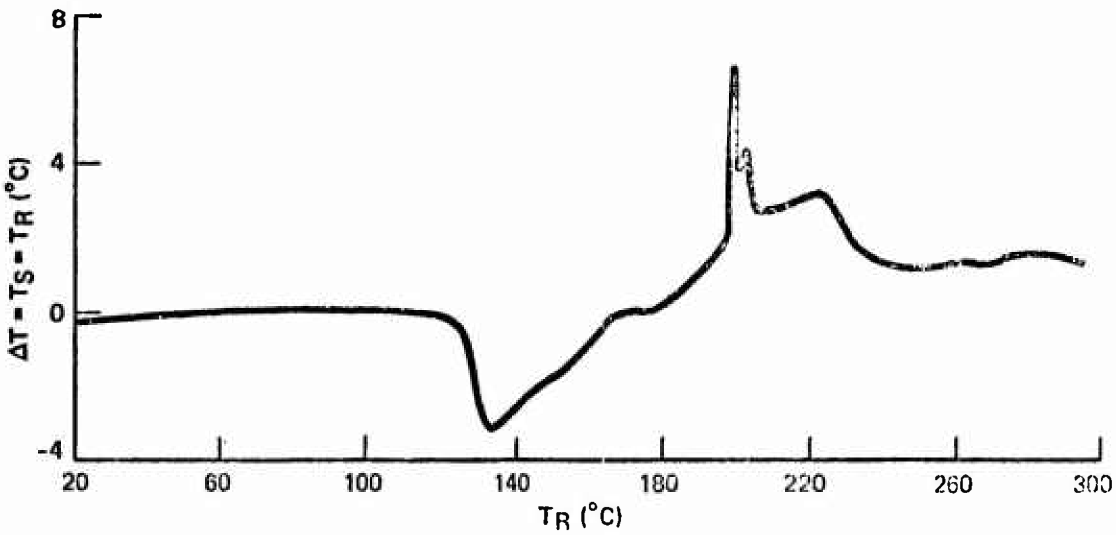


FIGURE 8. DTA RESULTS OF 3 GRAMS OF GSX TYPE II

2.2.3 Discussion.

The shape of the DTA curves varies considerably with the water content of the explosive; as these samples are quite hygroscopic, the water content can vary from 0% to 35% by weight depending on humidity. The evaporation of water during the heating of the sample tends to depress the curve a few degrese below the reference temperature; this is clearly demonstrated in Figure 6 between 40° to 140° C.

This effect has also been observed in GSX Type II and GSX Type III, although Figures 7 and 8 don't show it because the samples were relatively dry. The physical chemistry of evaporation and boiling in these systems is complicated because the explosive contains a water/ethylene glycol mixture with a high dissolved-solids content. Boiling of these explosives occurs at about 150° C for GSX Type I, 125° C for GSX Type II, and at 130° C for GSX Type III. All these explosives contain entrained air bubbles which, due to lessened viscosity and bubble expansion, migrate to the surface of the sample and give the appearance of boiling. In GSX Type I this occurs at about 120° C, while in GSX Type II and GSX Type III it occurs just before genuine boiling begins. The ability to hold entrained air bubbles at higher temperature is probably due to the stronger gel systems of GSX Type II and GSX Type III. Should the explosives encounter these temperatures during their manufacture or in the supply cycle, a resultant loss of sensitivity might occur due to loss of entrained air.

Decomposition of these explosives begins at about 185° C for GSX Type I, 160° C for GSX Type II, and 160° C for GSX Type III in dry samples. In samples of GSX Type II and GSX Type III with average or higher water content, the beginning of the decomposition exotherm is masked by the endotherms associated with boiling.

Figures 9, 10, and 11 show the results of DTA runs on GSX Type I, GSX Type II, and GSX Type III after being dried for 60 hours at 165° F. Figure 9 clearly shows the endotherm of melting (probably assiocated with the amine nitrates of the GSX Type I) noted during drying. (See "Weight Loss at 165° F.") Figures 10 and 11 clearly show the usual ammonium nitrate crystal transformations, and Figure 11 shows the melting endotherm for TNT. The exotherms of decomposition begin at around 160° C for GSX Type II and GSX Type III.

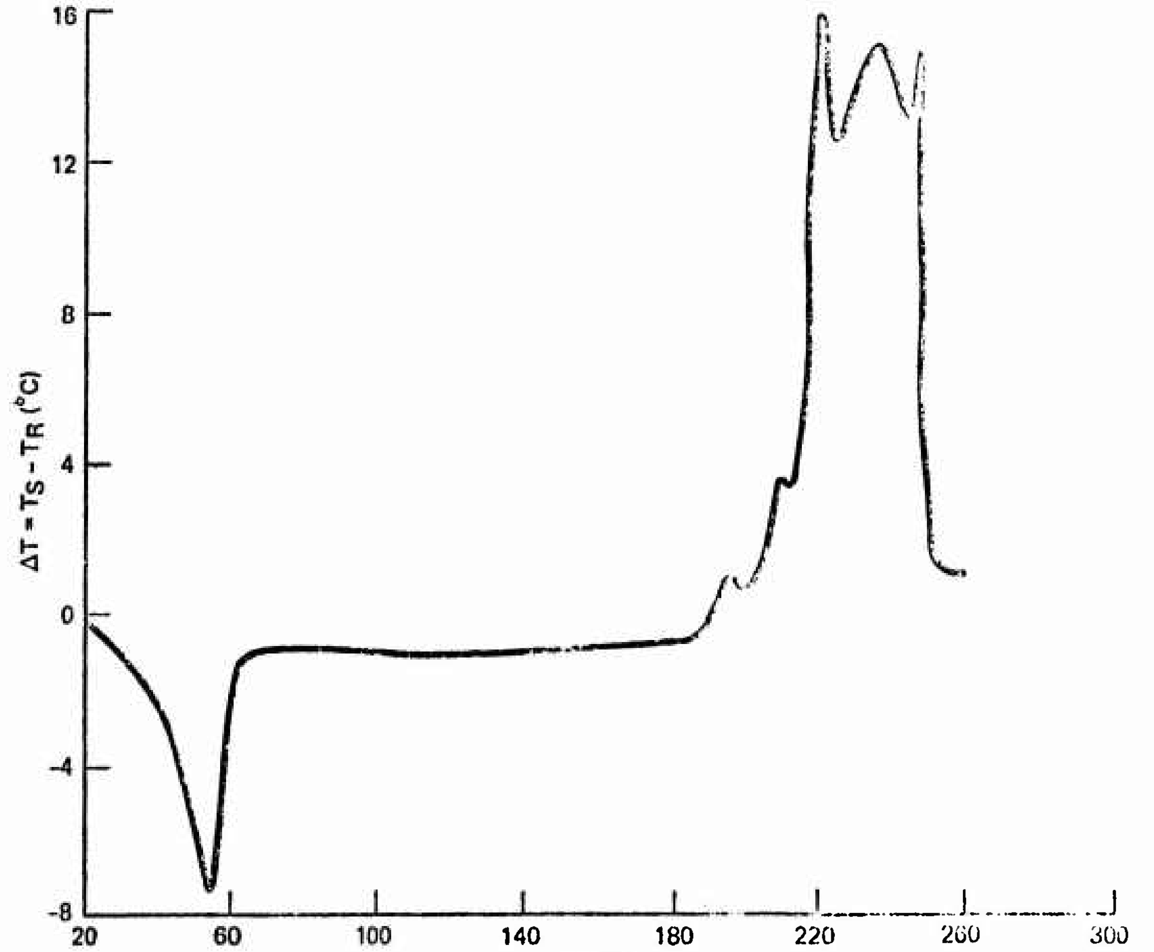


FIGURE 9. DTA RESULTS OF 2 GRAMS OF GSX TYPE I

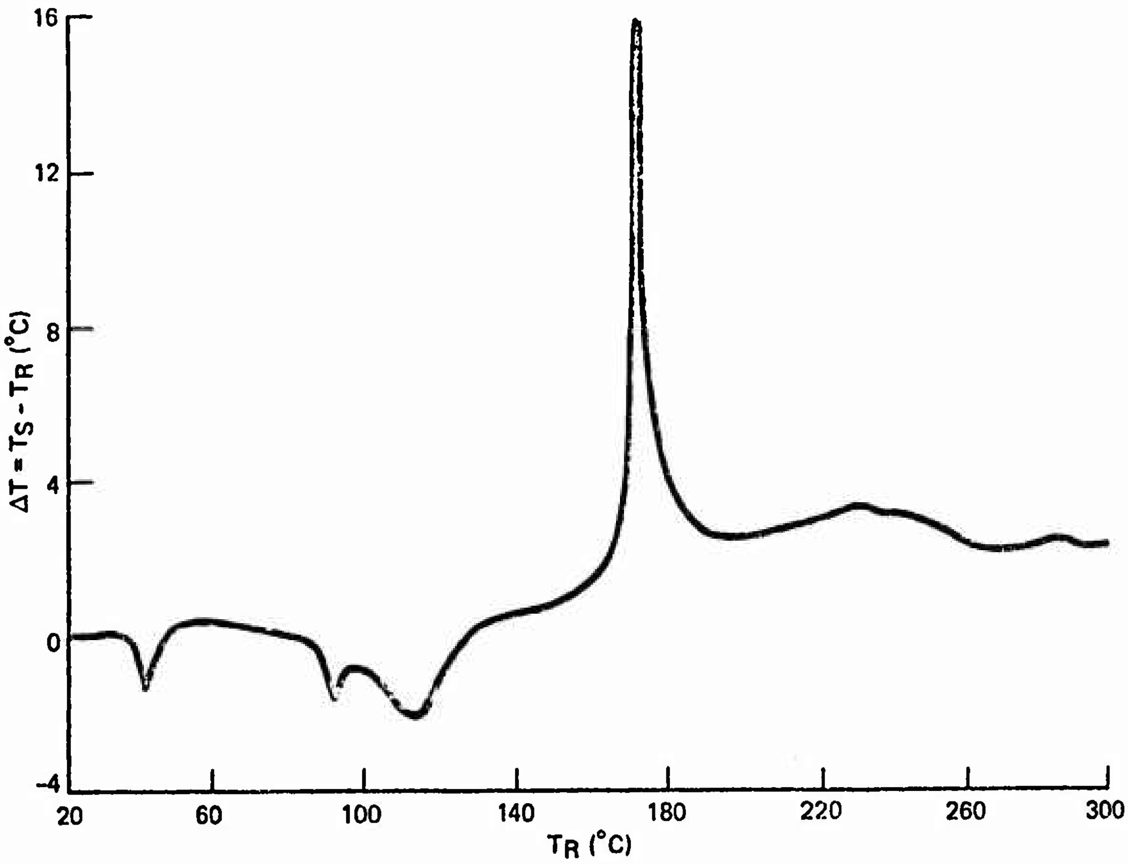


FIGURE 10. DTA RESULTS OF 2 GRAMS OF GSX TYPE II

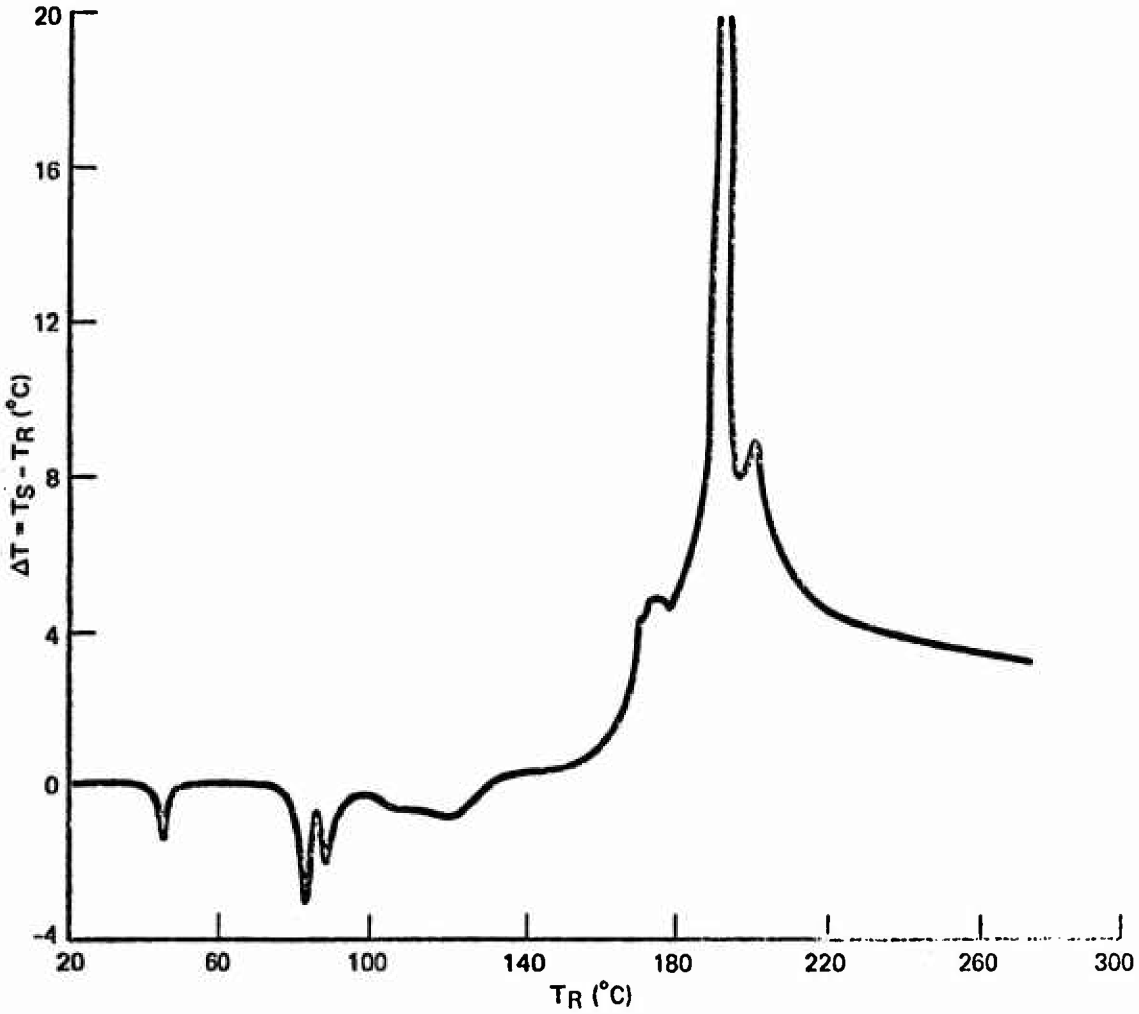


FIGURE 11. DTA RESULTS OF 2 GRAMS OF GSX TYPE III

2.3 TIME-TO-IGNITION TESTS.

These tests give a relative indication of an explosive's ability to withstand constant elevated temperature.

2.3.1 Procedure.

These tests are conducted like the DTA with one exception: the temperature of the reference sample is held constant instead of being increased uniformly. This temperature is selected by observing the behavior of the explosive as indicated by the DTA thermogram. A temperature just below the lowest exotherm is usually selected. This gives one the "worst-case" condition for thermal stability over a given period of time.

2.3.2 Results.

The results of the tests at 160° C are shown in Figures 12, 13, and 14. The results of the tests at 150° C are shown in Figures 15, 16, and 17.

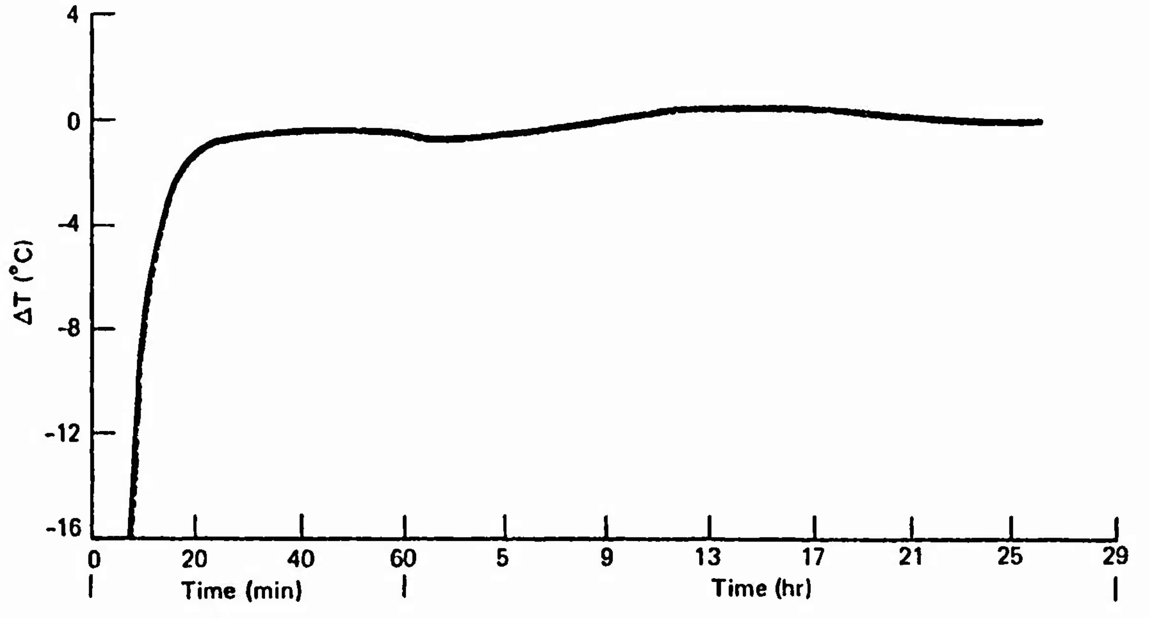


FIGURE 12. 160° C TIME-TO-IGNITION TEST RESULTS OF GSX TYPE I

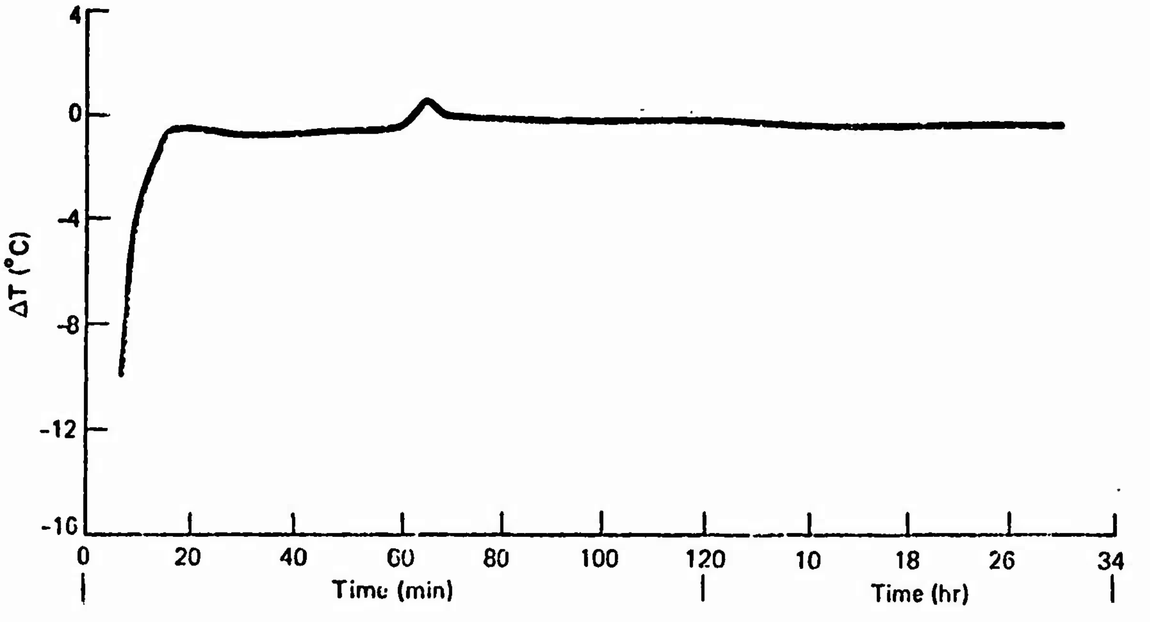


FIGURE 13. 160° C TIME-TO-IGNITION TEST RESULTS OF GSX TYPE II

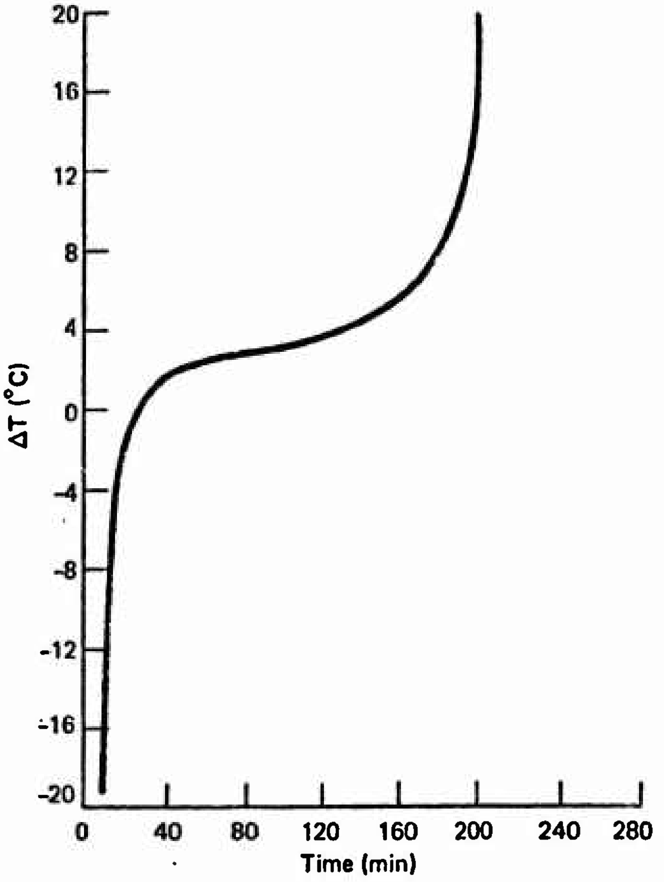


FIGURE 14. 160° C TIME-TO-IGNITION TEST RESULTS OF GSX TYPE III

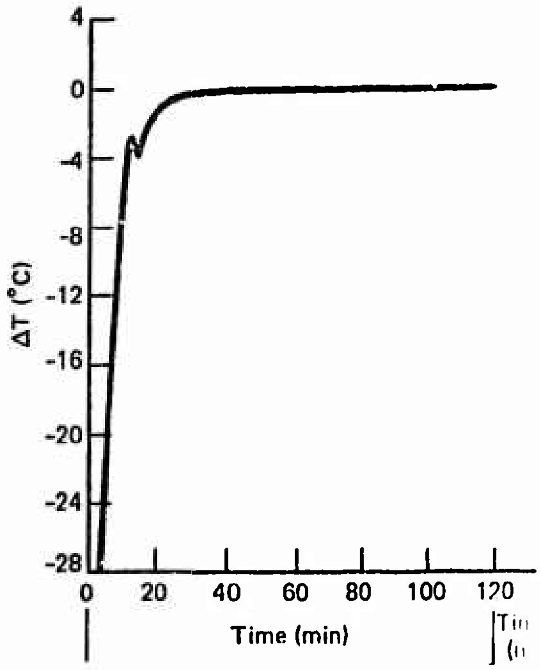


FIGURE 15. 150° C TIME-TO-IGNITIO: TEST RESULTS OF GSX TYPE II

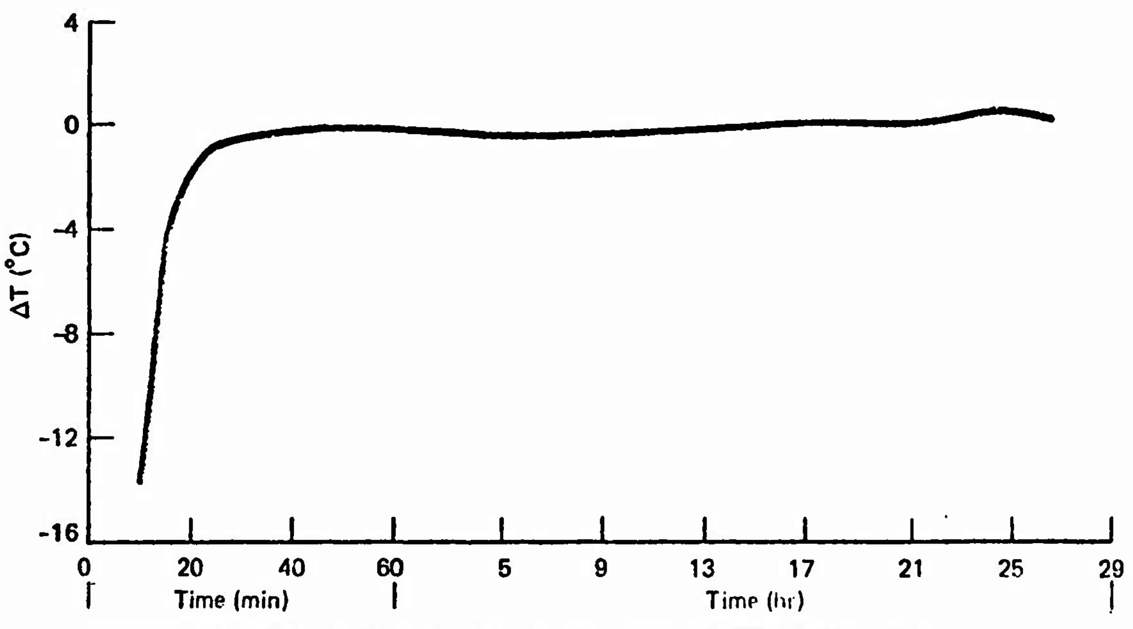


FIGURE 16. 150° C TIME-TO-IGNITION TEST RESULTS OF GSX TYPE I

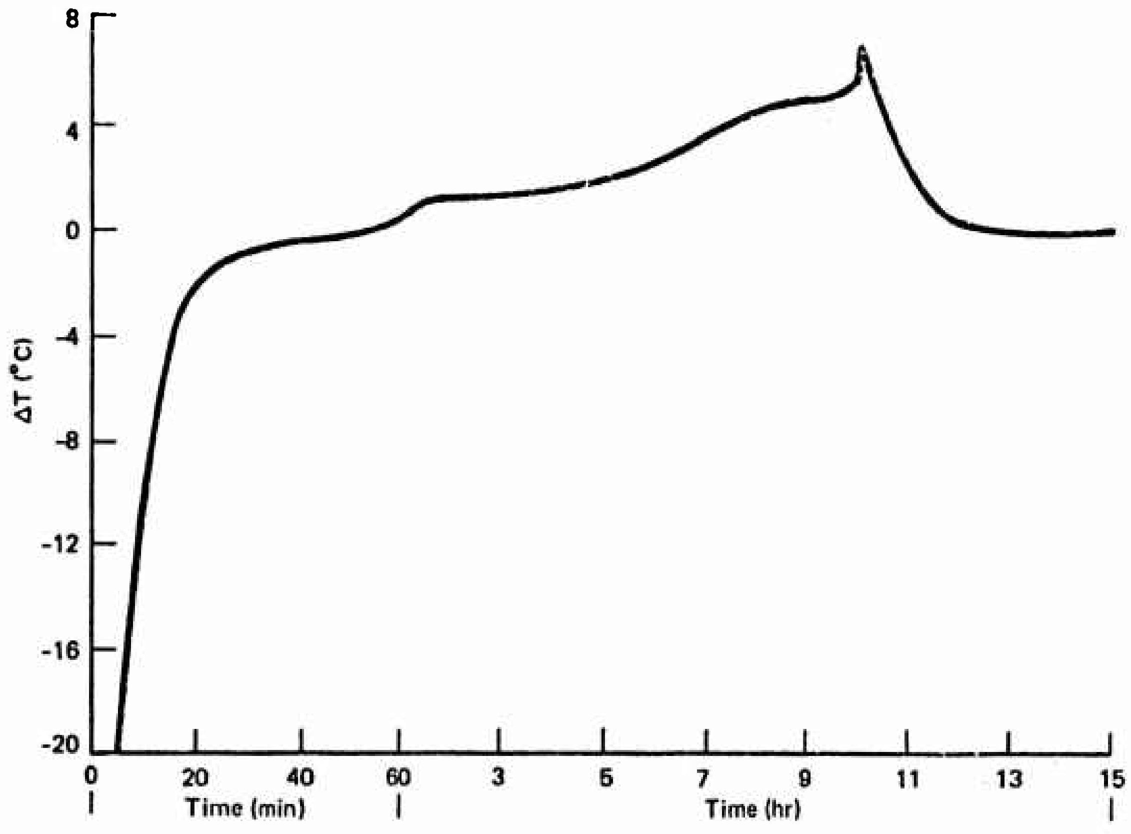


FIGURE 17. 150° C TIME-TO-IGNITION TEST RESULTS OF GSX TYPE III

2.3.3 Discussion.

GSX Type I and GSX Type II appear to be relatively stable at 160° C since no exothermic behavior was observed. However both samples showed evidence of having boiled off their volatile components. GSX Type III exhibited exothermic behavior at both temperatures. The sample container used in the test at 160° C showed evidence of rapid decomposition by the remaining residue. The residue in the 150 ° C test also indicated that decomposition had taken place though not as fast as at 160° C.

2.4 WEIGHT LOSS AT 165° F.

This test determines the compositional stability of the explosive with regard to its volatile component at elevated temperatures which might be encountered during the supply cycle.

2.4.1 Procedure.

This is a very simple test in which a precisely weighed amount of explosive is placed in a large oven at constant temperature (165° F in this case) and removed and weighed periodically for determination of weight loss. The container holding the explosive should have a close-fitting cover so that the sample can be sealed from atmospheric humidity during weighing. This precludes the pick-up of moisture due to the

hygroscopic properties of the explosive. The cover is of course removed while the sample is in the oven. A large oven should be used so that evaporation of volatiles does not increase, to any measurable extent, the partial pressures of the vapor phases in the oven atmosphere.

2.4.2 Results.

The volatile components of these formulations consist of water and ethylene glycol. After heating for 60 hours at 165° F, GSX Type I and GSX Type II lost 88% of these components, while GSX Type III lost 80%. These results are presented graphicallly in Figure 18.

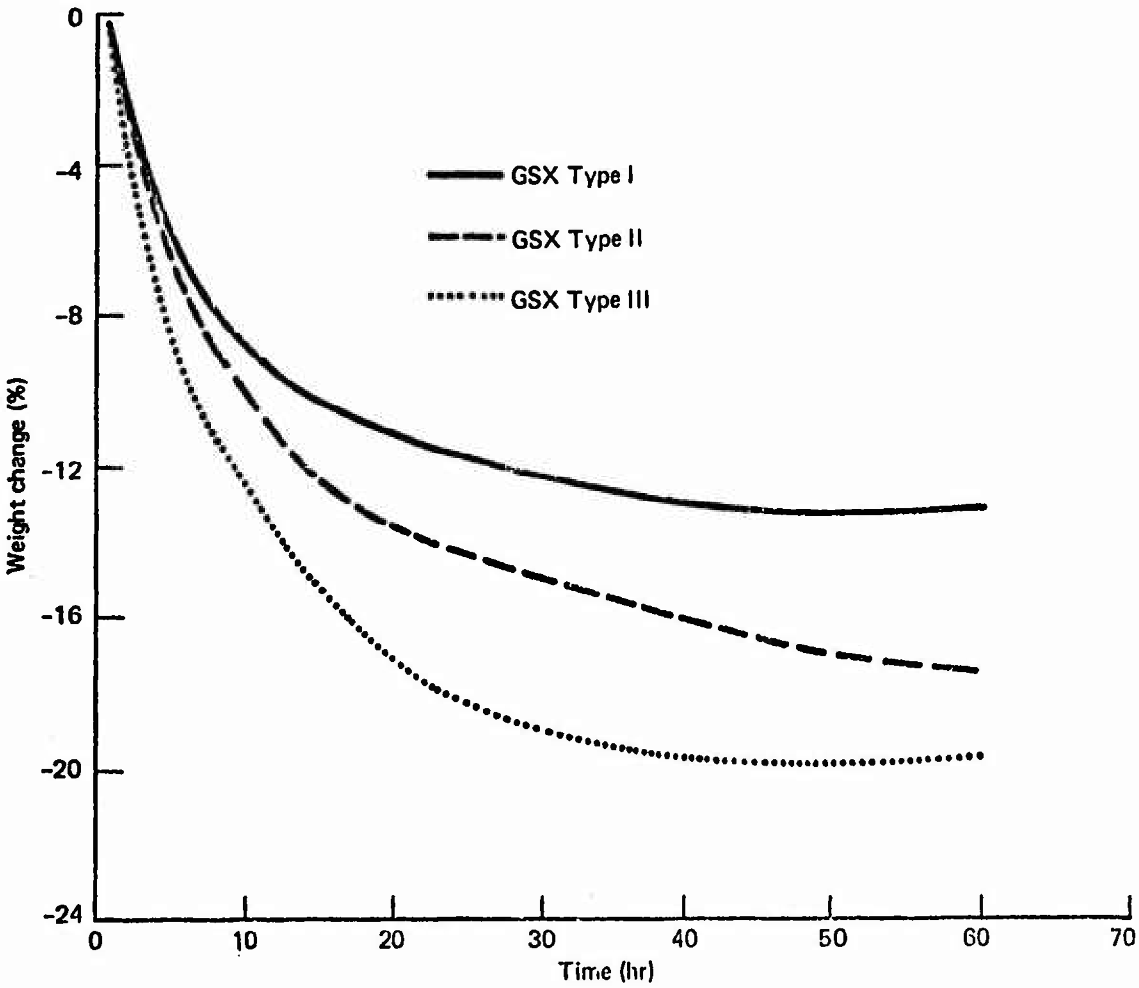


FIGURE 18. WEIGHT LOSS OF GSX EXPLOSIVES
EXPOSED TO AIR AT 165°F

When removed from the oven the GSX Type I was in a liquid state but solidified as it cooled during the weighing operation. At room temperature its appearance was that of a solid white amorphous mass with a crystalline cast to the surface. Crystals of ammonium nitrate had formed on the lumpy surface texture of GSX Type II and GSX Type III.

2.4.3 Discussion.

The melting of GSX Type I at 115° F could cause problems in ordnance not sealed for liquid explosive. The liquid would probably seep out of the case and contaminate magazine areas.

2.5 HYGROSCOPICITY TESTS.

These tests determine the effects of high (90%) and low (20%) relative humidity (RH) on the explosive in question.

2.5.1 Procedure.

Precisely weighed amounts of explosive are placed in a weighing dish which should have a close fitting cover. The controlled humidity environment is prepared in a large desiccator by placing an aqueous solution of sulfuric acid in the bottom where the desiccant normally would be. For 90% RH, a 59.2% solution of H_2SO_4 is used; for 20% RH, an 18.6% solution is used. The covers are removed from the weighing dishes, and then the dishes are placed in the desiccators. Periodically the samples are removed for weighing, during which time the covers are tightly replaced to avoid pick-up of atmospheric moisture.

2.5.2 Results.

The results of these tests are presented in Figures 19 and 20. After 264 hours at 20% RH, the weight losses were 6.1%, 17.5%, and 10.5% for GSX Type I, GSX Type II, and GSX Type III, respectively, while at 90% RH the weight gains were 54%, 36%, and 39.5%. The physical appearances of the samples after testing were as follows:

(1) GSX Type I at 20% RH – Viscosity of the sample increased from a quite fluid gel to a semi-solid gelatinous mass.

(2) GSX Type II and GSX Type III at 20% RH – Ammonium nitrate crystals formed on surface of the samples.

(3) GSX Type I at 90% RH – Sample became completely fluid with small entrapped air bubbles at the surface.

(4) GSX Type II and GSX Type III at 90% RH – Samples exhibited a marked decrease in viscosity with a local segregation of gelatinous fluid. These characteristics were much more pronounced in the GSX Type II.

2.5.3 Discussion.

It will be noted that the weight loss at 20% RH of GSX Type III (10.5%) is greater than the postulated formulation content (8.8%). This may be due to the sulfuric acid reacting with the ethylene glycol vapors or due to the possible pickup of additional water prior to testing by the hydroscopic nature of this explosive.

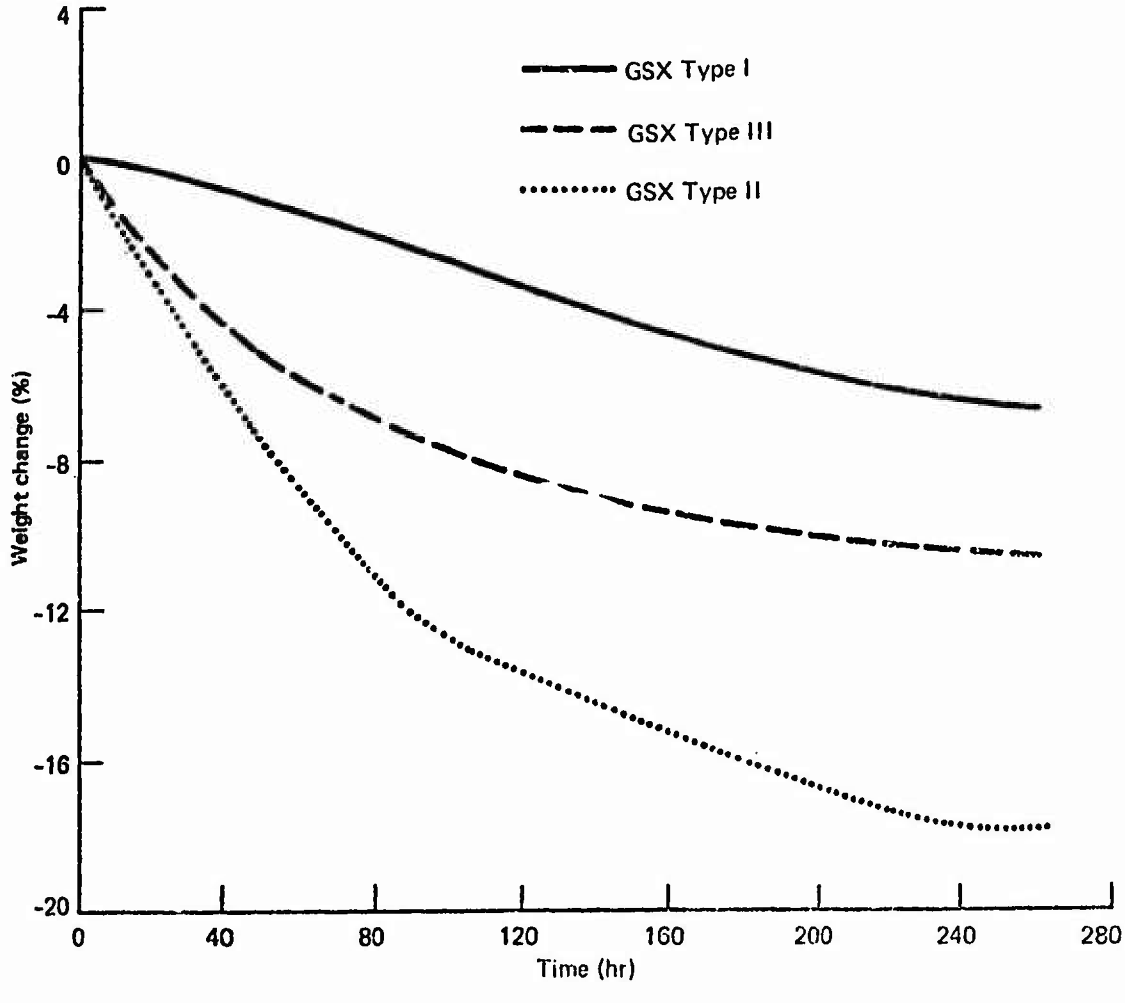


FIGURE 19. HYGROSCOPICITY TEST RESULTS AT 30° C AND 20% RELATIVE HUMIDITY

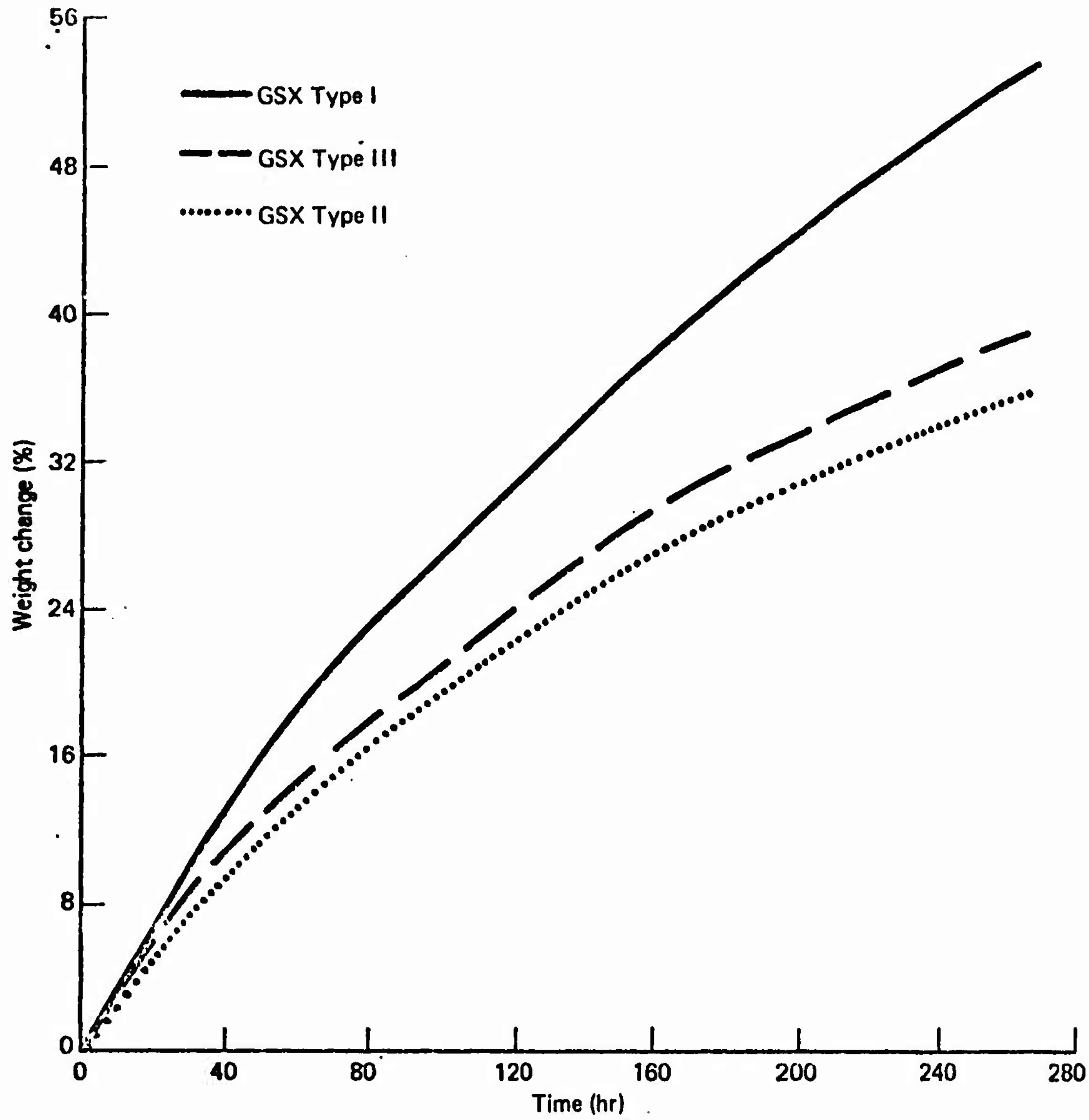


FIGURE 20. HYGROSCOPICITY TEST RESULTS AT 30° C AND 90% RELATIVE HUMIDITY

2.6 CONCLUSIONS.

All candidates are compositionally unstable in regard to their water content showing drastic fluctuations with both temperature and humidity. At 165° F and at 90% RH, GSX Type I becomes completely fluid and will require watertight ordnance cases. GSX Type II and GSX Type III are significantly better in this regard.

GSX Type III undergoes decomposition at 150° C while GSX Type I and GSX Type II are stable at 165° C. No difficulties are expected at temperatures lower than these.

Section 3

FIELD TESTING OF CANDIDATE GELLED SLURRY EXPLOSIVES

3.1 INTRODUCTION.

The field testing for the Alternate Bomb Fill Program was conducted at Camp A. P. Hill, Bowling Green, Va. A. P. Hill is a training camp set up for instruction and practice in the use of Army weapons. Our use of the testing area was on a noninterference basis with the regular range firings. Hence no permanent testing facility could be set up; all equipment had to be removed at the end of each test series.

3.2 FRAGMENTATION AND AIR-BLAST TESTS.

3.2.1 Test Description.

Two different types of tests were conducted—small scale fragmentation and large scale cold boostering tests. Initially, arena type tests determined average fragment velocity and the relative number of fragments for each candidate. Detonation velocity and over-pressure data were also obtained. Fragment data were obtained using three or four 4-foot X 12-foot X 0.02-inch thick aluminum witness plates located 20 feet from ground zero (Figure 21). Two high-speed cameras, a Fastax and a Hi-Cam, were used to record the detonation and the subsequent flash of the fragments penetrating the witness plates. The Fastax, running at 5,000 frames per second, gave good quality pictures for observing the shot while the Hi-Cam, at 10,000 frames per second, was used to determine the average fragment velocity. Timing marks were placed on both films at 1-msec intervals using a Wollensak pulse generator.

Side-on overpressure data were taken in the Mach Stem shock region using Kistler 701A pressure transducers with a model 553A miniature charge amplifier. Transducers were shock mounted in Delrin 637F adapters to reduce the effects of vibration. The output of the charge amplifier was displayed on a Hewlett-Packard 180A oscilloscope in the control trailer (2000 feet away) and photographed with a Polaroid camera. The oscilloscope was triggered at the time of detonation; both arrival time and peak overpressure were recorded.

Detonation velocity was recorded using DuPont T-2 target switches located 4 inches apart. As each switch closed, a capacitor was discharged through it; the resultant voltage output was displayed on Tektronix 545A oscilloscope and photographed. Timing marks were generated on the Z-axis of the oscilloscope at 1-μsec intervals using a Tektronix Type 181 time mark generator.

The explosives were loaded into steel pipes 20 inches long and closed at one end. These pipes, 4-1/2-inch ID by 5-1/2-inch OD, were manufactured from Type MT1015 seamless steel tubing with an elongation of 24% in 2 inches. A plane wave penolite booster, manufactured by the Naval Ordnance Laboratory at White Oak, Md., was used with an engineer's special blasting cap to initiate the explosives. Charges were detonated in the vertical position with the center being 6 feet above ground level:

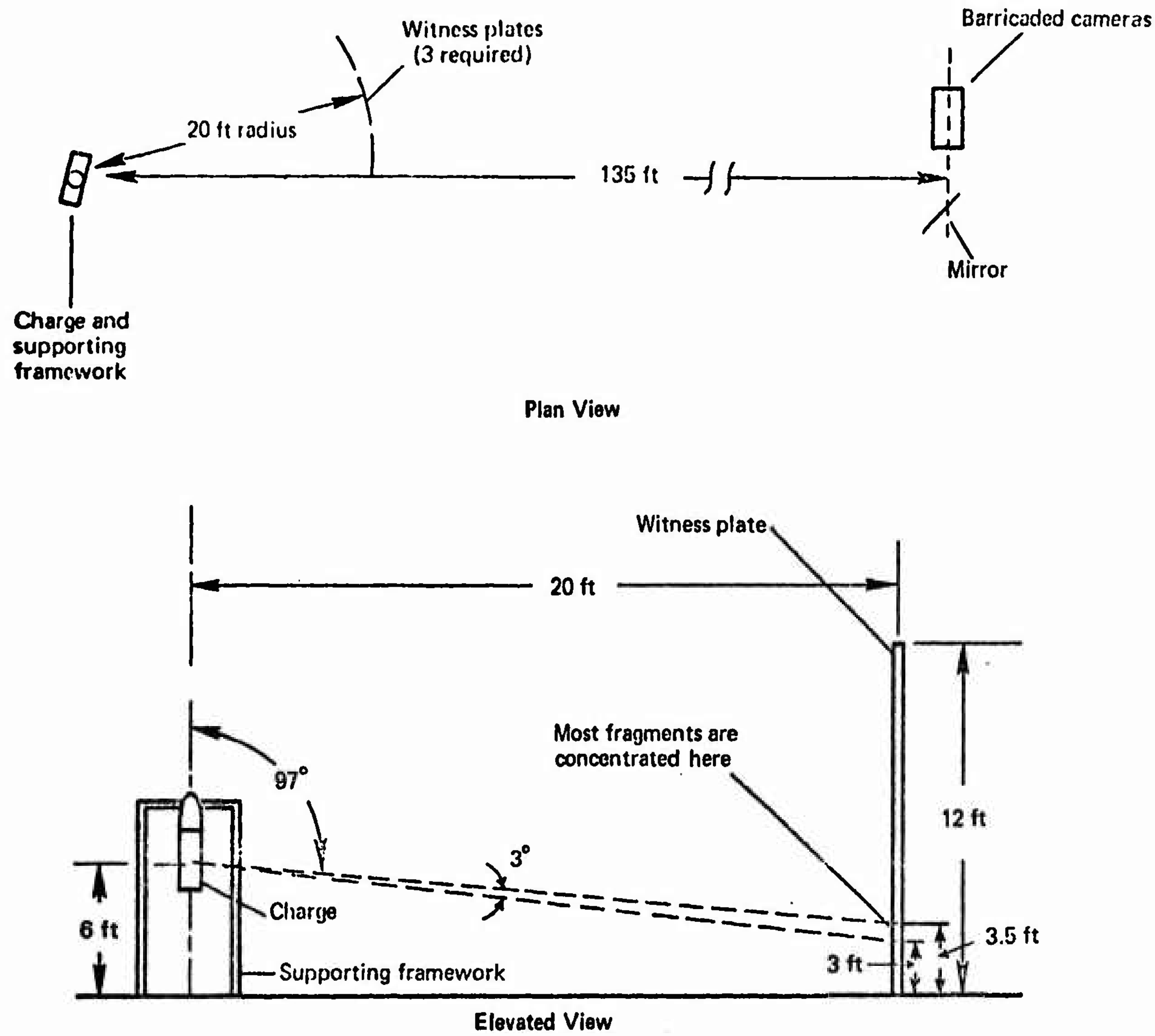


FIGURE 21. TEST SET-UP

3.2.2 Results.

The relative number of fragments produced was determined by counting the number of holes in each witness plate. The holes were grouped into four classes according to size. Class 1 was for holes too small to permit the passage of a 1/4-inch rod. Class 2 was for holes which were larger than 1/4 inch but would not permit passage of a 3/4-inch rod. Class 3 holes were larger than 3/4 inch but would not allow passage of a wooden block which was 3/4 inch wide by 1-1/2 inches long with corners rounded to 3/8 inch. Class 4 included all holes which would admit the wooden block.

Gurney constants were obtained using the equation

$$V_0 = G \left[\frac{c/m}{1 + 0.5\, c/m} \right]^{1/2}$$

where

V_0 = initial fragment velocity (m/sec)
G = Gurney constant (m/sec)
c = cross-sectional area of the explosive times the density of the explosive
m = cross-sectional area of the metal times the density of the metal.

Initial fragment velocity was determined by measuring the average velocity of the first fragment to strike the witness plates. It is the opinion of experts[1] in the field that this technique should be accurate to within 100 m/sec.

A sample of the arena data is presented in Tables I and II. Most of these tests were conducted at Camp A. P. Hill, Bowling Green, Va., on 19 through 28 November 1969.

Table I

ARENA TEST DATA

Test no. and explosive	Number of fragments			
	Class 1	Class 2	Class 3	Class 4
(1) GSX Type II	–	–	–	–
(2) GSX Type III	52	39	21	11
(3) GSX Type I	–	–	–	–
(5) H6	89	69	42	9
(6) H6	67	98	23	17

Table II

TEST DATA SUMMARY

Test no. and explosive	Date	Temperature (approx) (°F)	Detonation velocity (m/sec)	Normalized no. of fragments[1]	Normalized overpressure[1] (psi)	Gurney constant (m/sec)
(1) GSX Type II	1/28/69	35	3200	0.590	–	1980
(2) GSX Type III	11/25/69	45	5080	0.795	1.066	2190
(3) GSX Type I	2/4/69	35	–	0.470	--	1990
(5) H6	11/26/69	45	7340	1.000	1.000	2555
(6) H6	11/26/69	45	7430	1.000	1.000	2599

3.3 COLD BOOSTER-SENSITIVITY TESTS.

3.3.1 Test Procedure.

Cold boostering tests with Bombs Mk 82 Mod 1 were conducted at Camp A. P. Hill. These bombs were temperature conditioned to -75° F at the Naval Weapons Laboratory, Dahlgren, Va. On the morning

of the tests, bombs were removed from the cold boxes and put into special insulated containers for shipment to A. P. Hill. Just prior to firing, bomb temperature measurements were taken by inserting thermocouples through the nose fuze into the internal plumbing of the bomb. Bomb temperatures varied from -55° to -67° F.

Three types of fuzing systems were used. In the first tests, the Air Force FZU-2/B boosters were used with a wooden plug to stimulate the FMU series fuze. Later tests used FMU-35/B fuzes modified for static firing by Honeywell, Inc., Hopkins, Minn. The third type of fuze system used was the Navy M904E2 fuze with a T45E2 adapter booster modified for static firing with a blasting cap. The Air Force FZU-2/B booster contained 45 grams of RDX while the Navy fuze contained 270 grams of tetryl. Postfiring inspection after no-go tests indicated that all three fuzing systems had sufficient energy to shatter at least one-half of the bomb casing and scatter explosives over a wide area. On those tests which were not high order and required a clean-up shot, C-4 explosive was packed into the tail fuze well and detonated.

3.3.2 Results.

The GSX Type I with no aluminum and no high explosive (HE) was most difficult to initiate. The lowest temperature at which it could be made to detonate was 0° F. The test diameter was greater than 8 inches. Type II initiation became questionable at -40° F while GSX Type III with both HE and aluminum detonated at -65° F. The fourth material tried was the PBXW which could not be made to detonate even at 70° F. For comparison purposes, Minol-2 and Tritonal are easier to initiate than GSX.

Section 4

ANALYTICAL METHOD OF DETERMINING GELLED SLURRY EXPLOSIVE COMPOSITION

4.1 INTRODUCTION.

Attempts were made to develop analytical techniques to determine the compositions of gelled slurry explosives which could be used to determine the compositions of candidate formulations or to check for compliance with specifications.

The procedures developed to date are described below. Procedures were developed specifically for GSX Type I and GSX Type III types of formulations only. However, a procedure could be developed for GSX Type II by combining those of GSX Type I and GSX Type III.

4.2 PROCEDURE FOR THE SEPARATION AND ANALYSIS OF GSX TYPE III.

4.2.1 Nominal Composition.

Possible ingredients

Ammonium nitrate (NH_4NO_3)
Cyclonite (RDX)
Trinitrotoluene (TNT)
Ethylene glycol (EG)
Water
Aluminum
Gum
Boric acid

4.2.2 Sample Handling.

The sample is stored in a nonconductive container in a tote barricade behind a safety shield. A nonconductive spatula is used to transfer the sample into a tared weighing bottle equipped with a stopper.

4.2.3 Volatiles.

Five grams of the sample are weighed accurately to the nearest tenth of a milligram into a tared weighing bottle and placed into a vacuum desiccator over silica gel for 24 hours or until constant weight is maintained. The weight loss is calculated as the percentage of water.

4.2.4 Separation of Ingredients

Trinitrotoluene: The dried sample of blasting gel is placed into 20 ml of spectrograde benzene and allowed to stand for 30 minutes or until the trinitrotoluene is completely dissolved. The sample is decanted through Whatman no. 41 filter paper. Two more 10-ml aliquots of benzene are added to the sample to ensure complete solution of the trinitrotoluene. The residue is placed on the filter paper and pulled dry by gentle suction. The sample may be removed from the filter paper and placed into a tared dish to estimate the amount of trinitrotoluene removed from the sample. Residual benzene may be removed by placing the sample into the vacuum desiccator. The benzene and trinitrotoluene are made up to 50-ml volume and analyzed by Procedure A.

Cyclonite (RDX): The sample is removed from the vacuum desiccator and 20 ml of acetone are added to remove the RDX. The sample is stirred gently with the nonconductive spatula until the RDX is completely dissolved. After allowing the remaining ingredients to settle to the bottom of the container, the acetone is decanted through the previously used filter paper. Add two 10-ml aliquots and repeat the procedure. The total volume is made up to 50 ml with acetone and Procedures B, C, and D are followed for the determinations of RDX, ethylene glycol, and boric acid.

Ammonium Nitrate: The residual acetone is removed from the residue on the paper by using gentle suction. The sample is then placed into 20 ml of absolute methanol and allowed to stand for 30 minutes or until all of the ammonium nitrate has completely dissolved leaving the aluminum and the gum. The extraction is repeated with two 10-ml aliquots of absolute methanol and filtered. The final volume is made up to 50 ml. The determination of ammonium nitrate is made by Procedure E.

Aluminum and Gum: Since these are the only ingredients remaining, they are placed into 1:1 hydrochloric acid (HCl) to dissolve the aluminum. About 25 ml of 1:1 HCl should be added cautiously, dropwise until gassing subsides and the aluminum is completely in solution. The gum may be filtered off at this stage, dried, and weighed. The remaining filtrate is taken to 100-ml volume and Procedure F is followed for the aluminum determination.

4.2.5 Analytical Procedures for GSX Type III Ingredients.

Procedure A. Determination of Trinitrotoluene:

Reagents and Equipment

(1) Spectrograde Benzene
(2) 0.05-mm NaCl fixed cell
(3) Infrared spectrophotometer
(4) Trinitrotoluene.

Construct a calibration curve of absorbance versus mg/ml of trinitrotoluene in benzene using a 0.05-mm cell. The analytical wavelength is 13[illegible] cm^{-1}. The concentrations of the standard should be between 10 to 50 mg/ml or sufficient to give an absorbance of 0.2 to 0.4. The sample is diluted to give an absorbance in the same range and the measurement is made as in the calibration. The concentration of the sample is read directly from the calibration curve in mg/ml.

Calculation:

$$\% \text{ TNT} = \frac{C \times D \times 100}{S \times 1000} \text{ or } \frac{C \times D}{10S}$$

where

C = Concentration in mg/ml as read from the calibration curve

$$D = \text{Dilution factor} = \text{original vol} \times \frac{\text{final volume}}{\text{dilution aliquot}}$$

S = Sample weight in grams × 100 = mg.

Procedure B. Determination of RDX:[2]

Reagents

(1) Concentrated sulfuric acid, 95% to 98%, ACS

(2) Sulfuric acid (10:3)–add 1000 ml concentrated sulfuric acid to 300 ml distilled water; cool to room temperature

(3) Ferrous sulphate reagent–add 3 g of $FeSO_4 \cdot 7H_2O$ to a mixture of 55 ml distilled water : 5 ml concentrated sulfuric acid; stir until dissolved; add 200 ml concentrated sulfuric acid and cool to room temperature (Reagent will be good for 2 days.)

(4) Sodium hydroxide solution, 2.5%

(5) RDX washed with alcohol and dried at 80° C for 1 hour.

Prepare four 30-ml pyrex beakers. In two of the beakers, accurately weigh 5 to 10 mg samples o standard RDX. Into the third beaker, pipet a 1-ml aliquot of a 50-ml volume acetone extract of the gelled slurry explosive (5 g sample). The fourth beaker is for the blank determination. Take the aceto solution to dryness on a steam bath. Add 5 ml of the 2.5% sodium hydroxide solution to each beaker and heat on a steam bath without a cover glass until completely dry. Cool to room temperature. Add 10 ml of sulfuric acid (10:3), stir, warm to a temperature of 35° to 50° C until solution is complete. Cool to room temperature. Decant into a 25-ml volumetric flask (previously rinsed with 10:3 sulfuric acid). Rinse the beaker with 5 ml ferrous sulphate reagent and add to the volumetric flask. Repeat rinsing action with several small portions of ferrous sulphate to bring the flask to 25-ml volume. Measu the absorbance of the standard and the sample after 10 to 60 minutes at 525 mμ with a spectrophotometer set at 100% transmittance with the blank.

Calculation:

$$\% \text{ RDX} = \frac{\text{absorbance of sample} \times 100}{\text{absorptivity factor} \times \text{mg of sample}}$$

$$\text{Absorptivity factor} = \frac{\text{absorbance of RDX standard}}{\text{mg of RDX}}$$

Procedure C. Determination of Ethylene Glycol (Hydroxyl):[3]

Reagents

(1) Standard 0.1N sodium thiosulfate.

(2) Periodic acid reagent dissolve 5 grams of periodic acid in 200 ml distilled water; add 800 ml of glacial acetic acid; store in a dark bottle.

(3) Potassium iodide, 200 grams/liter.

(4) Starch indicator solution, 0.1%.

Take a 5-ml aliquot of the acetone solution containing the RDX, ethylene glycol, and boric acid to dryness. Wash the dried residue into a stoppered iodine flask with water. Add 50 ml of the periodic acid solution. Let it stand for 30 minutes at room temperature. Add 20 ml of potassium iodide solution and titrate the liberated iodine with 0.1N sodium thiosulfate. Set up two blank determinations.

Calculation:

$$\% \text{ ethylene glycol} = \frac{\text{ml of titer (blank sample)} \times 62.07}{\text{sample wt (g)} \times 20}$$

Procedure D. Determination of Boric Acid:[4]

Reagents and Equipment

(1) Standard 0.1N NaOH solution
(2) Phenolphthalein indicator
(3) Mannitol
(4) pH meter
(5) Glass-calomel electrode pair.

Take the remainder of the acetone solution to dryness. Add 50 ml of distilled water to the weighed residue. Adjust the pH to 4.0 and boil the solution for 3 minutes to remove and carbonate. Add 2 grams of mannitol, stopper, and cool to room temperature. Titrate to end point or to pH 11 with the pH meter and plot the titration curve of ml of NaOH verses pH.

One ml of 1N NaOH is equivalent to 0.06184 g of H_3BO_3.

$$\% H_3BO_3 = \frac{\text{ml NaOH} \times \text{normality} \times 0.06184 \times 100}{\text{sample wt}}$$

Procedure E. Determination of Ammonium Nitrate:[5]

Reagents and Equipment

(1) Reagent grade ammonium nitrate
(2) Absolute methanol

(3) 1.0 cm matched silica cells
(4) Bausch and Lomb 505 spectrophotometer or equivalent visible--ultraviolet instrument.

The absolute methanol solution contains most of the ammonium nitrate except for the small amount that dissolved into the acetone. This can be calculated from the solubility of ammonium nitrate in acetone (0.145 g in 100 ml).

Construct a calibration curve of mg/ml of NH_4NO_3 in methanol using approximately 3 to 6 mg/ml or enough to obtain an absorbance of 0.3 to 0.5 at 302 mμ wavelength. The sample is diluted to give the concentration in the same range. The concentration of NH_4NO_3 in methanol is read from the calibration curve in mg/ml.

Calculation:

$$\% \ NH_4NO_3 = \frac{C \times D \times 100}{S \times 1000} = \frac{C \times D}{10S}$$

where

C = Concentration in mg/ml of NH_4NO_3 from the calibration curve

$$D = \text{Dilution factor} = \frac{\text{original vol} \times \text{final volume}}{\text{dilution aliquot}}$$

S = Sample weight × 1000 = mg.

Procedure F. Determination of Aluminum:

Reagents and Equipment

(1) Hydrochloric acid (1:1)
(2) Platinum crucible
(3) Ammonium hydroxide
(4) Ammonium chloride wash solution, 2% in water.

Pipette a 10-ml aliquot of the sample solution into a 200-ml beaker. Add 100 ml of distilled water. Heat to nearly boiling. Neutralize to a methyl red end point with NH_4OH, added dropwise with stirring. Remove from heat, allow precipitate of $Al(OH)_3$ to settle, filter hot on medium paper and wash with hot NH_4Cl wash solution. Transfer filter paper to an ignited tared platinum crucible and ignite at 1100° C. Cool in a desiccator and weigh to constant weight. Al_2O_3 is 52.92% aluminum.

$$\% \text{ aluminum} = \frac{\text{wt of precipitate} \times 0.5292 \times 100}{\text{sample wt}}$$

4.3 PROCEDURE FOR THE SEPARATION AND ANALYSIS OF GSX TYPE I.

4.3.1 Nominal Composition.

Possible ingredients

- Ammonium nitrate
- Sodium nitrate
- Organic nitrate
- Water
- Gellant

The sample is handled and dried by the same procedure as used for GSX Type III. However, the sample size may be reduced to 3 grams since a longer time is required for drying. There are three very hygroscopic ingredients present.

4.3.2 Separation of Ingredients

The mixed organic nitrates were separated from the remaining ingredients. Since the constituents of the organic nitrate mixture are very similar in solubility properties a separation of them was not made. Twenty-five ml of acetone are added to the dried sample. Two liquid phases will appear. Both phases are filtered through Whatman no. 41 filter paper. Add two more 10-ml aliquots of acetone to the residue to remove completely the organic nitrates. After filtering, the top phase containing the acetone and organic nitrates is removed. Add 20 ml more of acetone to the bottom layer until the white crystals are thrown out of solution. Filter off the acetone and add the crystals to the residue for further washing. Follow Procedure A for the analysis of amine nitrates. The final volume may be made up to 100 ml.

Ammonium Nitrate: The residue is extracted with 20 ml of absolute methanol to remove the ammonium nitrate. Two 10-ml aliquots more are used to complete the extraction. The sample is filtered through Whatman no. 41 filter paper, and the filtrate is made up to 50-ml volume. Follow Procedure B for analysis.

Sodium Nitrate: The remaining residue contains the gellant and sodium nitrate. Remove the sodium nitrate by using 25 ml of 95% methanol. Repeat the extraction until all of the sodium nitrate has been removed. Final volume may be made to 100 ml. Follow Procedure C for analysis.

Gellant: After removal of the other ingredients, the gellant may be pulled dry under vacuum, placed into a tared weighing bottle, and dried at 150° C to constant weight.

4.3.3 Analytical Procedures for GSX Type I Ingredients.

Procedure A. Determination of Amine Nitrates:

A-1. Determination of Amine by Tetraphenyl Boron Precipitation[6]

Reagents and Equipment

(1) Sodium tetraphenyl boron (3% in distilled water, filtered)
(2) Hydrochloric acid (1:1, with distilled water)
(3) Wash solution (distilled water saturated with ammonium tetraphenyl boron)
(4) [illegible]

Pipet two 5-ml aliquots of the acetone solubles which have been taken to a total volume of 100 ml into 100 ml beakers. Evaporate the acetone from the sample in a vacuum desiccator. Dissolve the residue in 25 ml distilled water. Add 1 drop 1:1 hydrochloric acid. Add 25 ml freshly filtered 3% aqueous sodium tetraphenyl boron solution. Let stand 20 to 30 minutes before filtering through a tared extra fine crucible. Wash precipitate with distilled water saturated with ammonium tetraphenyl boron, freshly filtered. Dry at 105° C for 1-1/2 hours, cool, and weigh.

$$\% \text{ amine} = \frac{\text{wt precipitate} \times 0.0535 \times 100}{\text{sample wt in 5-ml aliquot}}$$

A-2. Determination of Nitrate by Nitron Precipitation(7)

Reagents

(1) Nitron reagent (10-g nitron in 100 ml of 50% acetic acid)
(2) Dilute sulfuric acid (10%)
(3) Crucibles (medium porosity).

Take a 10-ml aliquot of acetone solubles to dryness in a 150-ml beaker. Dissolve in 100-ml distilled water. Add 10 drops of dilute sulfuric acid. Heat nearly to boiling. Add 20-ml nitron reagent. Cool at least 2 hours or preferably overnight in a refrigerator. Filter through a medium porosity tared crucible and wash with ice water. Dry to constant weight at 110° C. Nitron is diphenylendianilohydrotriazole. The composition of the precipitate is $C_{20}H_{16}N_4 \cdot HNO_3$.

$$\% \; NO_3 = \frac{\text{wt precipitate} \times 0.1652 \times 100}{\text{sample wt in 10-ml aliquot}}$$

A-3. Determination of Carbon and Hydrogen by Elemental Analysis

The dried sample of amine nitrate is analyzed for carbon and hydrogen using the Coleman Carbon-Hydrogen Analyzer. About 3 to 5 mg of the sample are required. The samples must be completely dry and without residual solvent.

Procedure B. Determination of Ammonium Nitrate:

B-1. Ammonium Determination

Take a 2.0-ml aliquot of the ammonium nitrate-absolute methanol solution to dryness and follow Procedure A-1.

B-2. Nitrate Determination

Take a 10-ml aliquot of the ammonium nitrate-methanol solution to dryness or the equivalent of not more than 0.1 gram of HNO_3. Follow Procedure A-2 for determination of nitrate. The nitrate may also be determined by ultraviolet spectroscopy as shown in the analysis of GSX Type III, Procedure E.

Procedure C. Determination of Sodium Nitrate:

C-1. Sodium Determination by Atomic Absorption

Reagents and Equipment

(1) Standard sodium solution in 95% methanol, 1 ppm stock solution
(2) Perkin-Elmer 303 atomic absorption spectrophotometer or equivalent instrument
(3) Double distilled water.

Take an aliquot of the 95% methanol-sodium nitrate solution to volume, sufficient to give from 0.1 to 1.0 ppm sodium. Construct a calibration curve using from 0.1 to 1.0 ppm sodium in 95% methanol. The concentration of sodium is read directly from the calibration curve.

Calculation:

$$\% \text{ sodium} = \frac{C \times D \times 100}{S}$$

where

C = Concentration in ppm ($\mu g/ml$)
D = Dilution factor
S = Sample weight g $\times$ 1 $\times$ 10^6 = μg.

C-2. Determination of Nitrate by Nitron Precipitation

Take an aliquot of the sodium nitrate-95% methanol solution that would be equivalent to less than 0.1 gram of HNO_3. Follow Procedure A-2 for analysis of nitrate or use the ultraviolet method as in GSX Type III, Procedure E.

4.4 DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS.

The analytical procedures described are suitable for GSX Types I and III. A procedure for GSX Type II would include portions of each of the procedures described above and should require no further development. The accuracy of the methods is about ±2% of the quantity of each constituent.

The residue after all the extractions have been carried out is the remaining portion of the cross-linked gell system. Experience has shown that this residue contains most of the original gell material. Further work would be required to develop techniques to identify gell and stabilizer systems other than the boric acid systems used in GSX Type III.

If it is assumed that the organic nitrate of GSX Type I is a mixture of methyl and ethyl amine nitrates, the relative proportions of the two constituents could be determined from the amine or nitrate analysis and the carbon and hydrogen determination. If the mixture is more complex, an analytical method would be required for each component.

Section 5

LOADING CANDIDATE EXPLOSIVES INTO TEST CONFIGURATIONS

5.1 PROCEDURE FOR MIXING GSX.

Most GSX can be mixed by combining the dry ingredients (usually metal powder, prilled ammonium nitrate, and sensitizing agents) with a hot (140° F) solution of ammonium and/or sodium nitrate in any type of vessel under agitation. The gellants are added in the amount and at the appropriate time in the mixing cycle to obtain the desired end product.

5.2 PROCEDURE FOR MIXING PBXW.

The mixture is made in five cycles, each at 90° F and slow mixer speed (approximately 17-1/2 rpm). A typical mixer would be a 150-gallon Baker-Perkins vertical.

5.3 PREPARATION AND LOADING OF SAMPLE CONTAINERS.

5.3.1 Preparation of Sample Containers.

Wall thickness measurements were made ultrasonically on all bomb cases to be used for fragmentation testing. Likewise the radii of curvature for the ogive and boattail sections of the Mk 82 case were measured. These data are of no value to this report but are available at Indian Head should a need arise.

Hot melts, epoxy coatings, thermocouples, and other instrumentation were installed in sample containers, when required, according to the instructions of the laboratory conducting the tests on the particular samples.

Bomb cases were strapped into special loading carts which held them in a vertical, nose-down position and permitted movement from one building to another. Base rings were removed, and exposed threads were taped to prevent contamination with explosive.

5.3.2 Loading Sample Containers.

Samples were loaded by pouring the required amount into the container and allowing them to harden. The GSX Type I, however, does not harden and can be poured out of the container if desired. The fluidity of the GSX Type I has presented problems by leaking out of some containers, particularly bombs.

5.3.3 Postloading Procedures.

Containers were sealed in accordance with special intructions from the receiving laboratories. No special sealing methods were used with bombs. The base rings were simply replaced and properly tightened. They were then painted, stenciled, and appropriately packaged for shipment to the requesting laboratories.

5.3.4 Results.

Only Types I and II were observed to leak from bombs. Since the PBXW is a castable explosive with a plastic binder no leakage was expected. Type III benefits from a very stiff gellant and, thus, did not give any leakage. Leakage of Type I can be attributed to its fluidity. The cause of the leakage of Type II is more obscure since it also has relatively stiff gellant. It is currently felt that the leakage was caused by a phenomenon called syneresis, whereby excessive cross-linking of the gellant causes the gel-matrix to shrink, thereby squeezing out the water and some water soluble products. This supernatant liquid can then leak out of nonwatertight containers. A number of solutions to this problem are possible. The most desirable would be a slight reformulation of the gell-system to eliminate liquid phases. Others would be modifications to the bomb case and/or loading techniques to make the finished product watertight; this might include wax pads over the explosive and O-ring seals at the base rings.

REFERENCES

(1) Private communication with V. P. Phillipchuck, Naval Weapons Laboratory, Dahlgren, Va.

(2) G. Norwitz and M. Galn, "Semicro Spectrophotometric Determination of RDX and HMX," Microchemical Journal, Vol. 14, (1969), pp. 71-79.

(3) S. Siggia, Quantitative Organic Analysis Via Functional Groups. London, Chapman & Hall, Ltd.: John Wiley & Sons, Inc., 1949, pp. 8-9.

(4) Scott's Standard Method of Analysis, Vol. I. Princeton, N.J.:D. Van Nostrand Co., Inc., 1962, pp. 221-222.

(5) J. H. Wetters and K. L. Uglum, "Direct Spectrophotometric Simultaneous Determination of Nitrite and Nitrate in the Ultraviolet," Anal. Chem., Vol. 42, No. 3, (1970), pp. 335-340.

(6) R. Belcher and C. L. Wilson, New Methods in Analytical Chemistry. New York:Reinhold Publishing Corporation, 1955, p. 260.

(7) Scott's Standard Method of Analysis, Vol. I. Princeton, N.J.:D. Van Nostrand Co., Inc., 1962, p. 740.

SAFETY TESTS OF EXPLOSIVES TRANSPORT TRUCKS

Moderator:

Alvin D. Wiruth
Naval Weapons Center
China Lake, California

TESTS OF EXPLOSIVES TRUCKS

For many years explosives, propellants and other hazardous materials have been transported aboard the Naval Weapons Center in trucks modified to provide added protection to personnel hauling such materials. A protective flash shield constructed of 1/4 inch steel plate has been placed between the cab and the truck bed. The effectiveness of this shield has not been tested. It has become of increasing concern to personnel of the Safety Department that too much faith is being placed in the protection that these shields might provide in event of inadvertent ignition of explosives materials being transported.

To determine, at least quantitively, the amount of protection these shields would give, a series of tests were planned. Various amounts of several materials placed in trucks under conditions that occur daily in transporting explosives materials aboard the Center were ignited or detonated and the results assessed.

Five trucks that had been "surveyed" were obtained from the Transportation Division of Public Works. These trucks were fitted with beds and shields as are required for all explosives hauling vehicles. The trucks were placed in a semicircular array in the test area of the Explosives Ordnance Evaluation Branch of the Propulsion Development Department.

A series of 5 tests were planned

(1) Burn - 600 pounds, bulk propellant
(2) Burn - 50 pounds, pyrotechnic flare
(3) Detonation - 2 pounds, H.E. (comp C-3 block)
(4) Detonation - 10 pounds, H.E. fragmentation warhead (comp C-3)
(5) Detonation - 50 pounds, H.E. (PBXC-104) fragmentation warhead

On the day before the tests were to be run, mannequins dressed in coveralls, safety glasses and hard hats, were placed in the drivers seat of four of the trucks and an anthropomorphic dummy was placed in the other truck (Test #5). Thermocouples were installed in the truck cab for the two burn tests and pressure pickups were placed in the truck cab for the 2 pound detonation. The test charges were placed in each of the trucks in turn and photographic coverage (still and motion) made of conditions for the tests. Photographic coverage was also made during the test and showing damage after the tests.

Test Conditions and Results

All tests used a 1/2 ton pickup truck except No. 4 which was a 3/4 ton truck. All trucks had gasoline in the tanks except the truck in Test No. 5 from which the gas tank had been removed. All trucks had 1/4" thick steel shields between the cab and the bed of the truck that

extended the full height of the cab. The shield was 4 feet wide for Tests 1, 3 and 4 and 4 1/2 feet wide for Tests 2 and 5.

Firing

All test firings were done in accordance with the General Operating Procedure for the test area. All personnel were located inside the Control Building during firing, and remained in the building until the area was cleared by the test conductor. The firing and all cameras were actuated at the control panel. The tests were observed by means of two closed circuit TV monitors.

Test No. 1

Burn test of 600 pounds of bulk propellant, double base and fluorocarbon in wooden boxes with lids.

Method of Ignition

Make two spirals of quickmatch. Attach to two Electric Matches. Embed in fluorocarbon propellant. Also wrap two or more wraps of Quick Match around double base 1" x 30" rods, 2 each and connect to two Electric Matches and place rod in bottom of each of two boxes.

Instrumentation

Three thermocouples were installed inside the cab of the truck (1) on seat beside mannequin, (2) taped to face of mannequin and (3) taped to hand of mannequin.

Results

After ignition, burning continued for 2 or 3 seconds when an explosion or low order detonation occurred. Propellant was scattered over a wide area - up to 298 feet from the truck, much of it did not burn. The bed of the truck was destroyed with pieces being thrown as far as 234 feet. The steel shield was blown against the back of the cab and then slid down onto the bed of the truck. The inside of the cab was completely gutted by fire including the mannequin. The thermocouple attached to the face of the mannequin rose to 529°F in 4 seconds and then failed mechanically. The thermocouple attached to the hand rose nearly as rapidly to 300°F, dipped slightly and then reached to 410°F about 10 seconds after the start of the test. The thermocouple on the seat beside the mannequin reached 130°F in four seconds, then decayed slowly.

The right rear wheel was blown off; the left rear burned on the truck. Neither of the front wheels or tires were damaged. There was little evidence of fire in the engine compartment or front of the truck even though the hood was blown open by the blast.

Discussion

It is doubtful that persons in the cab could have escaped without rather severe burns, if at all. There was no measurement of blast pressure since only a burn was desired. This test, however, gave good evidence that we cannot expect hazardous materials to react in accordance with our plans. The unplanned reaction was due either to too strong ignition or too great a confinement of the propellant.

Camera Coverage

24 frames per second
64 frames per second
400 frames per second
20 frames per second Hulcher
black and white stills before and after
35mm color before and after

Test No. 2

Burn test of 50 pounds of pyrotechnic material - 1 Briteye Flare candle in a wooden box placed near the rear of the bed in the normal hauling location.

Method of Ignition

Electric match.

Instrumentation

Same as for Test No. 1.

Camera Coverage

Same as for Test No. 1.

Results

The flare burned for about five minutes. It burned through the aluminum truck bed but there was little evidence of any other materials burning. The steel shield appeared to be undamaged. The truck was observed on the TV monitors for about 15 minutes after the flare stopped burning and since there was no further evidence of burning all personnel left the area for lunch. A short time later (estimated to be less than 15 minutes) the residual heat again ignited combustible materials of the truck, including cab interior, engine compartment and tires. The truck was completely burned when personnel returned to the area about 1 1/2 hours later. The three thermocouples in the cab did not show any temperature rise during the time the flare was burning.

Discussion

It is certain that personnel could have safely left the cab without suffering any severe burns. If the flare had been located near the front of the truck bed the possibility of sustained burns would have been greatly increased.

Test No. 3

Detonation, 2 pound demolition block of Comp. C-3 in box placed on bed of truck just behind the driver. The width of the shield will be limited to a width that would not create a hazard to normal driving.

Method of Initiation

One Engineers Special Blasting Cap.

Instrumentation

3 pressure transducers were installed in the cab, (1) on back of seat behind driver, (2) one on seat beside driver and (3) one on dashboard in front of steering wheel.

Camera Coverage

See Test No. 5.

Results

Detonation was high order and complete. The complete left side of the bed was torn loose and peeled back from the bed. The right side rear pulled back to the fender area. The tail gate was torn loose and blown 68 feet to the rear of the truck. Other pieces of the truck metal were blown up to 70 feet from the truck. The lower corner of the steel shield was pushed into the cab below the drivers seat with sufficient energy to tear a hole in the metal of the cab. The welded aluminum bed was torn and pulled back at the front cameras. A 32 sq. inch hole was blown through the bed of the truck in the location where the block had been. Although the pressure transducers didn't show any pressure there was evidence of severe pressure rise within the cab. The window in the rear of the cab was pushed outward and several cracked. It was still in place but torn loose from bottom mounting. The windshield was cracked and the frame pulled loose. The mannequin was thrown against the steering column, the hard hat had been torn loose from the head band that was still on the mannequin. The roof of the cab showed evidence of being pushed up slightly and buckled at the right front cover.

Discussion

There is no doubt that personnel in the cab would have sustained some injury due to displacement in position. Although the transducer showed no pressure there was indication of pressure in the cab that might have caused ear damage or at least discomfort.

Test No. 4

Detonation. Sidewinder Fragmentation Warhead loaded with 10 pounds of Comp. C-3 in a wooden box located near the rear of the truck bed.

Method of Initiation

A 3/4" x 3/4" tetryl booster and Engineers Special Blasting Cap.

Instrumentation

None

Camera Coverage

See Test No. 5.

Results

The truck bed was completely blown from the truck. Both rear wheels and tires were severely damaged. The steel barriers shield was torn loose and pushed in the back of the truck cab forcing the mannequin against the steering column with sufficient force to break the steering column. The back of the seat was blown partially through the windshield which was almost completely blown out. The gas cap was blown off, the gas tank punctured near top with evidence that some gas had spilled out and burned on the ground beside the truck. There was no other evidence of burning in this test. The hood was blown off. Pieces of the truck were blown up to 262 feet from the truck.

Discussion

There is little doubt that any persons in the truck cab would have been fatally injured.

Test No. 5

Detonation, Shrike Fragmentation Warhead loaded with 50 pounds of PBXC-104, in a wooden box located near the rear of the truck bed.

Method of Initiation

A 1" x 1" tetryl booster and Engineers Special Blasting Cap.

Instrumentation

None.

Camera Coverage

24 frames per second
64 frames per second
400 frames per second
4000 frames per second
8000 frames per second
70 frames per second
Black and White stills before and after
35mm color before and after

Results

All of the truck aft of the cab was completely blown apart with pieces blown up to a distance of 681 feet from the location. The remainder of the truck and the mannequin were completely burned by the fire resulting from the blast.

Discussion

Any personnel in or adjacent to the truck would have been fatally injured.

Conclusions

1. Whenever possible the material being hauled should be located to the rear of the bed of the truck.

2. The shield will offer some protection in event the material burns and probably provide additional time for persons to leave the truck cab.

3. A shield of greater width would probably provide some more protection against larger fires.

4. The shield offers some protection from a detonation of small amounts of explosives.

5. With the cab windows closed additional protection would be provided from the initial flash and flames curling around the shield and cab.

6. A truck with doors opening toward the front of the vehicle would provide additional protection during exit from the cab.

7. Wing panels on each side of the shield extending toward the rear of the truck bed could help deflect flames away from the cab doors.

8. When the results of ignition are directional, the items may be oriented in the truck bed to reduce exposure to persons in or leaving the truck bed.

9. The shield will not protect against large amounts of material but is useful for smaller quantities.

10. Additional tests will be necessary to determine maximum amounts for which the shields will offer protection. Other parameters such as the wing panels mentioned in No. 7 above should be tested.

Discussion

Discussions after the presentation indicated that very little work has been done in this area. Many attendees have asked for information and the loan of the slide presentation. One person had done some limited work on protection of operating personnel. He had used several layers of cyclone fencing that was held only at the top allowing the bottom to swing free. He said he had initiated an explosion attempting to penetrate the fencing with 100 3/8" bolts. He indicated the fencing did not allow the penetration of any bolts.

This concept may be attempted along with the other possible tests outlined in the paper.

CONTAINERIZATION OF EXPLOSIVES

Moderator:

John R. Warren
Military Traffic Management and Terminal Service
Washington, D. C.

CONTAINERIZATION OF EXPLOSIVES

(Progress - Problems - Prospects)

SUMMARY PART I

Growth of Containerization

Mr. H. K. Holman, Transportation Engineering Agency, Military Traffic Management and Terminal Service

During the past few years the rapid growth in the use of intermodal containers by private industry has been paralleled by a tremendous expansion in the use of container services by the Department of Defense (DOD). During the past two fiscal years, the percentage of DOD export cargo moving in containers has increased from about 12 percent to over 30 percent. Currently, about 33 percent of the total dry and reefer export cargo is shipped in containers. This represents about 13,000 containers per month transporting 400,000 measurement tons of cargo to deployed forces overseas. By the end of FY 71 approximately 50 percent of all containerizable export cargo will be moving in containers. This amounts to over 50,000 containers per quarter. In the long run, nearly all containerizable cargo will move in containers. 80 percent of all DOD dry and reefer export cargo potentially falls in this category.

Ammunition makes up the largest percentage of containerizable cargo, about 12 percent of the total. While currently, this commodity moves in breakbulk ships, all agencies of the DOD concerned with ammunition shipments are now engaged in a coordinated effort to develop a system for the safe and economical movement of ammunition in containers. The potential benefits to the Government include reduced pipeline time due to reduced port handling and transit times, increased port capability and ship utilization, and reduced loss and damage.

SUMMARY PART II

Project TOCSA (Test of Containerized Shipments for Ammunition)

Mr. R. A. Shriver, Headquarters, Military Traffic Management and Terminal Service

Project TOCSA constituted the first overseas movement of ammunition in intermodal containers. The test was conducted as a joint endeavor by the Army and Navy and took place over the period 5 December 1969 through 20 January 1970.

The concept employed for this test shipment entailed direct delivery of 226 container loads of artillery projectiles and powder charges, rockets, and small arms ammunition from CONUS sources of supply to ammunition depots and supply points in Vietnam. Containers were loaded and extensively blocked and braced in CONUS at four Army ammunition plants and one depot for movement by highway to the Naval Weapons Station, Concord (Port Chicago California). The containers were loaded aboard the self-sustaining containership SS AZALEA CITY (Sea-Land, Inc.), transported to Cam Ranh Bay, Vietnam and further distributed by highway convoy and barge to ammunition supply depots and forward supply points within Vietnam. In every instance the ammunition was received in perfect order.

Project TOCSA clearly demonstrated the feasibility of shipping ammunition in containers to forward supply points in a combat zone overseas. From an operational standpoint, results of the test were most favorable from the point of terminal handling activities in CONUS through to final delivery at forward ASPs. The container ship loading/unloading was accomplished in less than one day as opposed to 5 to 7 days for loading/unloading a breakbulk ammunition ship. This fast port handling not only reduces safety hazards in the terminal area but also affords great potential in increasing port capabilities, particularly during contingencies. Economically the most significant results were achieved in terminal operations with potential reductions evident in pipeline costs and overseas depot operations. The 1st Logistical Command in Vietnam reported that handling of the containerized ammunition was 2 - 8 times less than that for breakbulk ammunition shipments. Particularly appealing was the fact that all ammunition was received at the depots and forward gun sites in perfect order.

On the other hand, cost and operational disadvantages were evident in the following areas:

1. Use of the 35-foot container coupled with the Coast Guard imposed 15 LT load limit resulted in poor cube utilization (26%) of the containers.

2. High costs in terms of material and manhours for extensive blocking and bracing of container contents to satisfy Coast Guard requirements. Also contributing to these high costs was the extra handling required at the ammunition plants because of their rail oriented loading facilities.

3. High CONUS line haul costs were incurred since loaded containers did not satisfy requirements of the Bureau of Explosives for rail movement. Accordingly, we had to negotiate motor carrier rates to encompass "deadhead" return of tractors to their home terminals.

4. Removal of the extensive blocking and bracing at destination was a formidable and time-consuming task. It took an average of 45 minutes to unload a container. Conventionally shipped ammunition delivered to

forward areas via Army stake and platform trailer is unloaded in only 15 minutes.

In view of the operational success of Project TOCSA the Assistant Secretary of the Army (I&L) directed the Army to start immediately on development and implementation of a total system technique for the containerized shipment of ammunition from CONUS sources to overseas consumption points. The Army Materiel Command (AMC) was tasked with development of the Operations Plan (OPLAN) for this total system approach. This OPLAN was approved by the Assistant Secretary of the Army on 27 July 1970. The plan envisions a three-phase accomplishment of the total system concept by 1975 as follows:

Phase I (Dec-Jan 1970): Move ammunition in rail boxcars (plants are not geared to economically load containers) to a port for stuffing into Army-owned 20 foot MILVAN containers equipped with mechanical dunnage. Containers will be loaded aboard a self-sustaining container ship for movement to Vietnam and distributed to inland depots and supply points.

Phase II (1972: Have capability to stuff MILVANS at some ammunition plants to permit use of container on flat car (COFC)/trailer on flat car (TOFC) service to port. Load on self-sustaining ship.

Phase III (1973-1975): Modernization of ammunition plants to permit efficient container loading for either motor or COFC/TOFC movement to the port. Modernization of ammunition plants to permit full container handling capability. Use of a specially designed ammunition container to facilitate field transportability. World-wide intermodal movement capability.

SUMMARY PART III

Mr. H. K. Holman, Transportation Engineering Agency, Military Traffic Management and Terminal Service

The Transportation Engineering Agency recently completed a study designed to set forth the transportability characteristics that a container should have for the safe and economical transportation of ammunition. The study analyzed ammunition dimensioning and flow data, various container configurations, cube and weight utilizations; transportability criteria for all modes; road, rail, and ship limitations; and safety regulatory requirements. Conclusions were that a Department of Defense ammunition container should meet the following criteria:

a. A rugged 8-foot by 8-foot by 20-foot demountable van that can be transported intermodally.

b. Minimum internal volume of 990 cubic feet with minimum door widths and heights of 90 inches and 85 inches, respectively.

c. Gross loaded maximum weitht of 44,800 pounds with a tare weight not to exceed 6,400 pounds, including the internal restraint system.

d. Capable of coupling together in units of two to form a 40-foot unit.

e. Compatible with the MILVAN chassis for over-the-road movement.

f. End loading and side loading on both sides.

g. United States of America Standards Institute (USASI) corner fittings on all corners.

h. Structured in steel, aluminum, fiberglass reinforced plywood, or reinforced plastic.

i. Sufficient structural strength to withstand appropriate static and dynamic load and impact shock and racking stress tests. Capable of with-standing the weight of five like containers, loaded to gross weight capacity, in a stacked configuration.

j. Ventilated, weatherproof, and corrosion resistant.

k. Internal mechanical load restraint system.

l. Door locking device handles with provisions for padlocking and customs sealing.

m. Capable of use with a detachable, cushioned underframe for road and rail movement.

EXPLOSIVE CLASSIFICATION AND HAZARD EVALUATION
OF PYROTECHNIC COMPOUNDS AND END ITEMS
UNDER TRANSPORT, PROCESSING, AND STORAGE CONDITIONS

Moderator:

W. P. Henderson
Edgewood Arsenal
Maryland

BLANK PAGE

DATA SYSTEMS FOR HAZARDS TESTING

William T. Stone

General Electric Company
Management and Technical Services Department

A detailed study of General Electric Management and Technical Services, Materiel Testing and Research Subsection (GE-MTSD-MTR), instrumentation and data acquisition, reduction, and processing requirements needed to support the hazards testing of pyrotechnic and explosive materials, resulted in the development of two systems - a telemetry data system and a hardwire transient data system:

- The Telemetry Data System which is utilized for medium to slow speed acquisition, consists of a standard IRIG telemetry system. The output of the portable VHF transmitter is communicated to the telemetry receiving station and then routed to either an analog magnetic tape recorder or through an analog to digital converter (ADC) on to a SDS-930 computer. This system enables data analysis to be performed in real time.
- The Hardwire Transient Data System is utilized for acquiring high speed data (e.g., pressure data resulting from a high-order detonation). This system consists of a Biomation Model 610 Transient Recorder which gathers and holds input data from applicable transducers and then transfers the data via conversion equipment to punched paper tape which is eventually input into the SDS-930 computer for analysis.

Both systems utilize a SDS-930 special purpose computer and the necessary peripheral equipment for simultaneous and independent data reduction on a priority interrupt basis. Data processing may be accomplished in real time

from telemetry receivers for quick look purposes or in pseudo-real time utilizing computer controlled playback of wideband telemetry tapes. Also post data reduction and analysis can be performed in batch processing mode. Data processing outputs consist of digital tapes and line printer tabulations. The Stromberg-Carlson Film Plotter (SC 4020) independent processing subsystem, using the off-line film plot preparation program, outputs data in the form of annotated plots and alphanumeric tabulations on 35mm film and hard copy paper. This subsystem has the capability to generate extensive and many varied plots and crossplots of massive quantities of data which are salient concepts to performing data analyses. The software consists of an integrated multiple program system capable of sequentially receiving, handling, storing, and outputting large quantities of data to automatically generate fully correlated engineering analysis.

INTRODUCTION

A detailed study of General Electric Management and Technical Services, Materiel Testing and Research Subsection (GE-MTSD-MTR), instrumentation and data acquisition, reduction, and processing requirements needed to support the hazards testing of pyrotechnic and explosive materials, resulted in the development of two systems - a telemetry data system and a hardwire transient data system:

- The Telemetry Data System which is utilized for medium to slow speed acquisition, consists of a standard IRIG telemetry system. The output of the portable VHF transmitter is communicated to the telemetry receiving station and then routed to either an analog magnetic tape recorder or through an analog to digital converter (ADC) on to a SDS-930 computer. This system enables data analysis to be performed in real time.
- The Hardwire Transient Data System is utilized for acquiring high speed data (e.g., pressure data resulting from a high-order detonation). This system consists of a Biomation Model 610 Transient Recorder which gathers and holds input data from applicable transducers and then transfers the data via conversion equipment to punched paper tape which is eventually input into the SDS-930 computer for analysis.

Both systems utilize a SDS-930 special purpose computer and the necessary peripheral equipment for simultaneous and independent data reduction on a priority interrupt basis. Data processing may be accomplished in real time

from telemetry receivers for quick look purposes or in pseudo-real time utilizing computer controlled playback of wideband telemetry tapes. Also post data reduction and analysis can be performed in batch processing mode. Data processing outputs consist of digital tapes and line printer tabulations. The Stromberg-Carlson Film Plotter (SC 4020) independent processing subsystem, using the off-line film plot preparation program, outputs data in the form of annotated plots and alphanumeric tabulations on 35mm film and hard copy paper. This subsystem has the capability to generate extensive and many varied plots and crossplots of massive quantities of data which are salient concepts to performing data analyses. The software consists of an integrated multiple program system capable of sequentially receiving, handling, storing, and outputting large quantities of data to automatically generate fully correlated engineering analysis.

DATA HANDLING SYSTEM (FIGURE 1)

The Data Handling System (DHS) consists of two high speed SDS-930 special purpose computers and the necessary peripheral equipment for simultaneous and independent data acquisition and reduction on a priority (interrupt) basis. The computers may be programmed to operate in a master/slave or independent mode and are capable of sharing their individual 16K memories. Equipment setup and checkout is accomplished, under program control, prior to any acquisition or processing of data.

The primary function of the DHS is the conversion and recording of PAM, PCM, and FM/continuous analog telemetry data for subsequent evaluation and data analysis. Data processing may be accomplished in real time from telemetry receivers for quick look purposes, or in pseudo real time utilizing

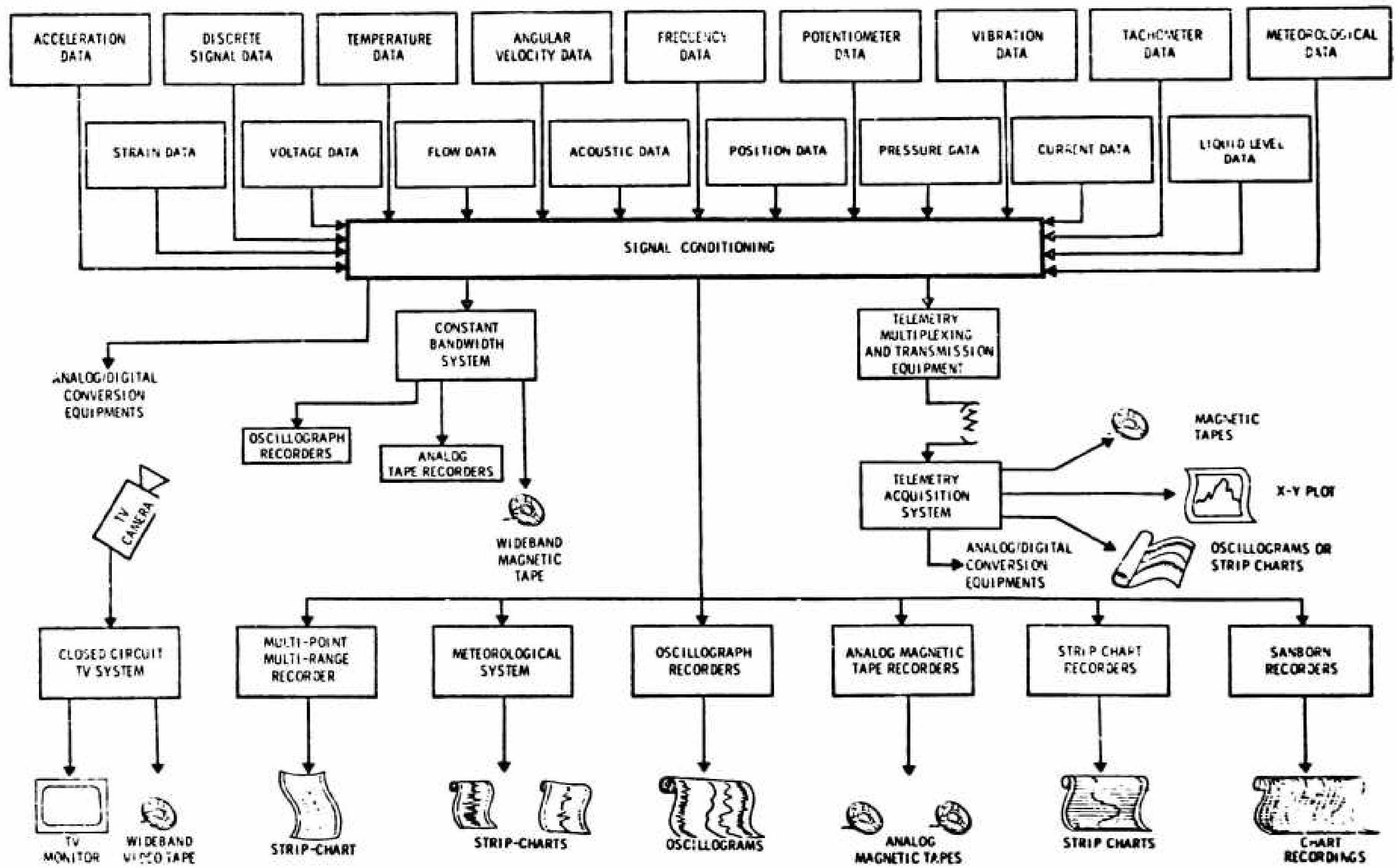


FIGURE 1. DATA HANDLING SYSTEM

computer controlled playback of wideband telemetry tapes. Also post data reduction and processing can be performed in a batch processing mode.

The total application is limited by software capability. Any data recorded on analog tape, IBM compatible digital tape, paper tape, or cards can be input and processed. Present DHS hardware and software processes and outputs data in such form as:

- Annotated plots of amplitude versus frequency.
- Annotated point plots as a function of time or as a function of data from another channel.
- Alphanumeric tabulations of data in forms of averages, limits, discretes, standard deviations, tolerances, etc.

TELEMETRY DATA SYSTEM (FIGURE 2)

The Telemetry Data System is utilized for medium to slow speed data acquisition in support of GE-MTSD-MTR's Pyrotechnic Hazards Classification and Evaluation Program. The system consists of a standard IRIG telemetry system interfaced with a SDS-930 computer. The primary function of this system is the conversion and recording of continuous analog telemetry data for the subsequent engineering analysis and evaluation. Also data processing is achieved in real time for quick-look purposes and in pseudo real time utilizing computer controlled playback.

REMOTE-TELEMETRY-CONTROL ACQUISITION SYSTEM (FIGURE 3)

GE-MTSD-MTR data acquisition requirements consists of unique data sampling

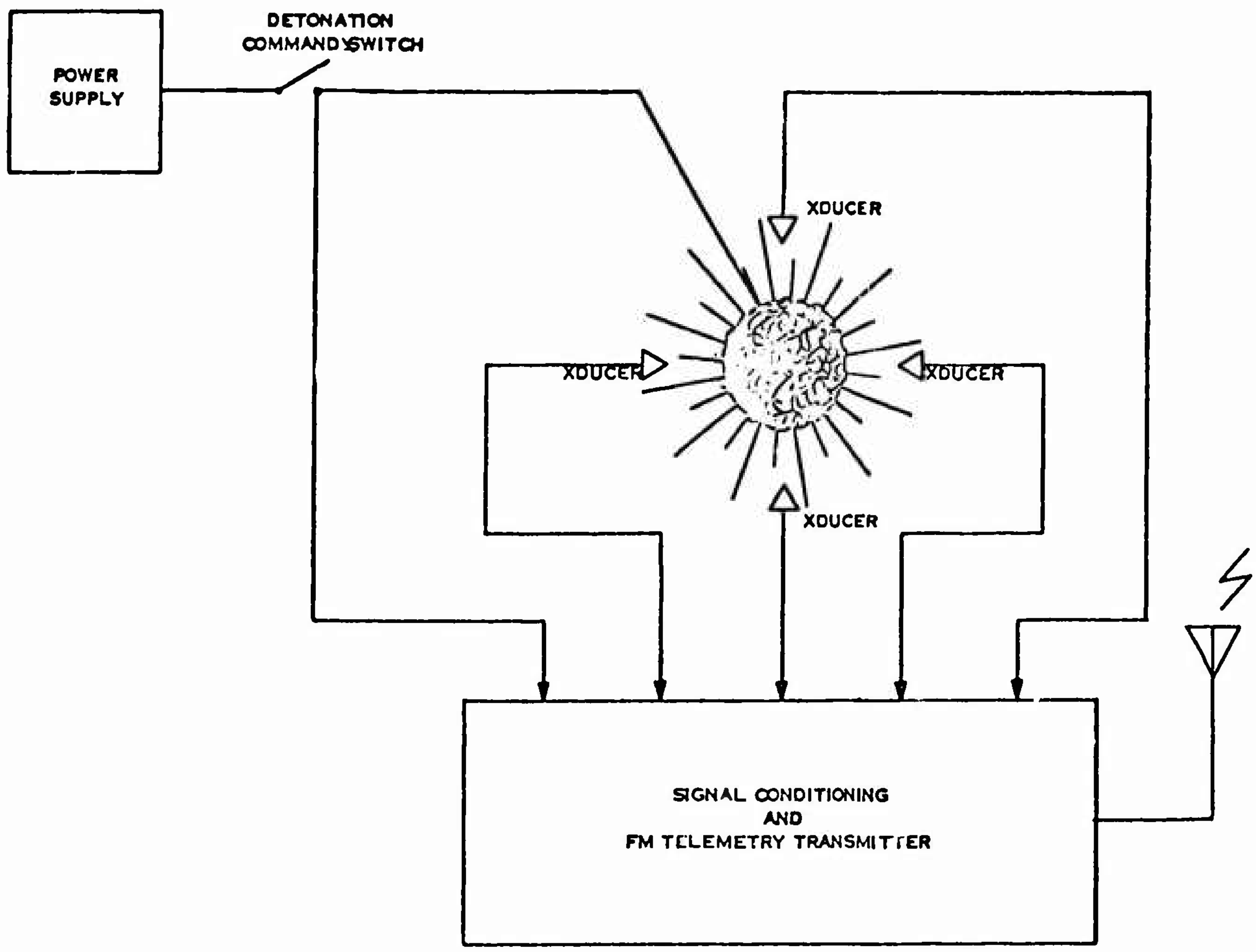


FIGURE 2. TELEMETRY SYSTEM

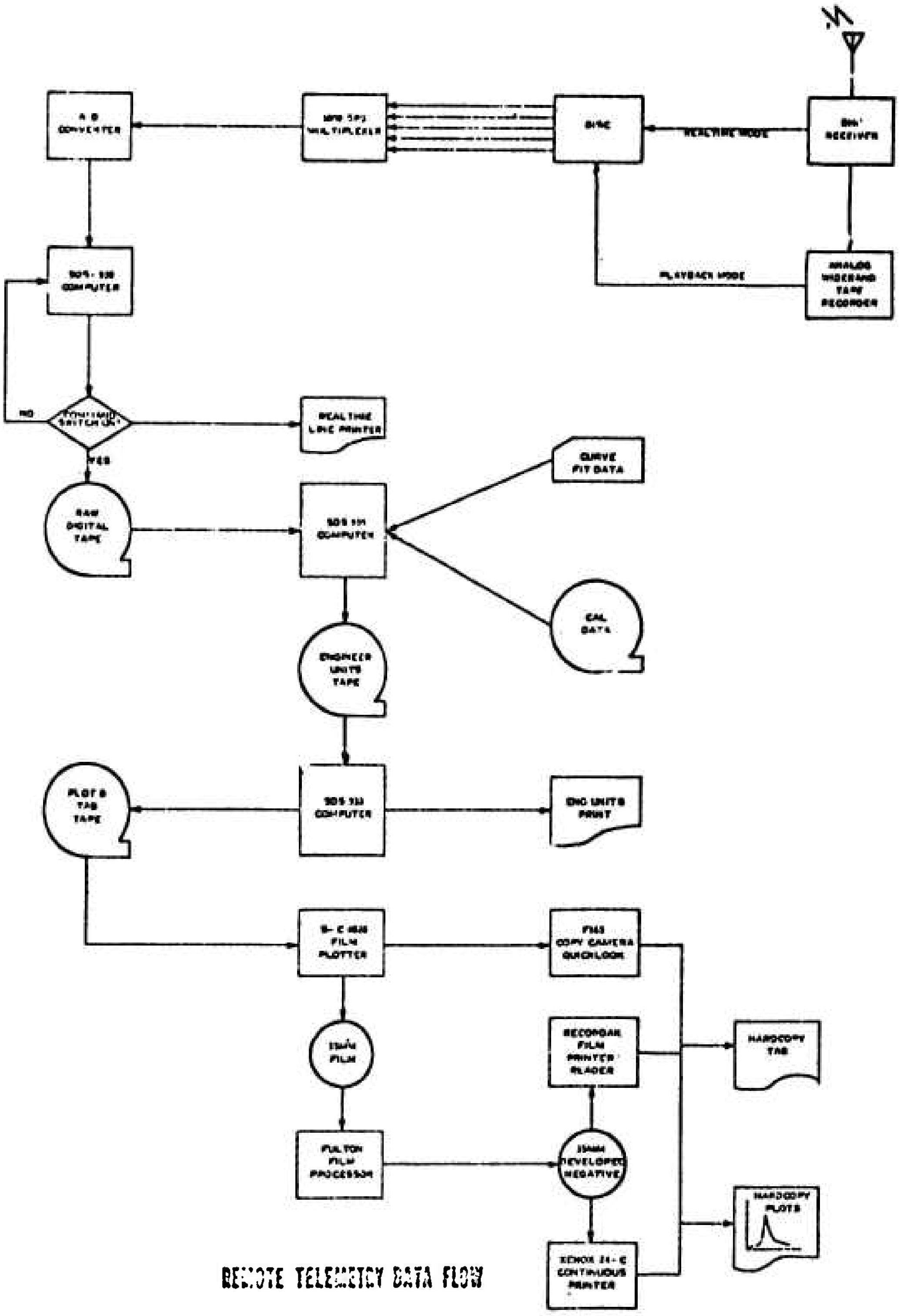


FIGURE 3. REMOTE-TELEMETRY-CONTROL ACQUISITION SYSTEM

requirements of events which occur at random intervals over an expanded period of time. The method of data acquisition involves instrumenting the transducers and the detonation command switch to a FM transmitter located at the test range and transmit the data to the DHS. The DHS may record the data on wideband tape or go directly into the SDS-930 computer for real time acquisition. Whether the computer is used real time or latter in a wideband playback mode does not affect the method of detection and digital recording.

Theory of Operation

Whether playback mode or real time, the computer will digitize the incoming data at 10,000 or 1000 samples per second (sps) and monitor the detonation command switch and record digital data only when the switch has been activated. The digital recording will stop when the detonation command switch is turned off. This method allows the test conductor in the field to control the Digital Acquisition System without operator intervention at the DHS.

System Advantages

The Remote-Telemetry-Control Acquisition System limits the amount of digital data tapes recorded for reduction. At the high sample rate required to observe the experiment (1000 sps), the amount of digital tape required for total (eight hours) of recording is not feasible. However, by using the remote control method of monitoring the command switch, the digital recording will be active only during the brief periods of experiments, and without close coordination between the test conductor in the field and the DHS.

TELEMETRY SOFTWARE

The software capability presently exists which provides the remote control

acquisition capability. Software capability also exists to convert the data to engineering units and provide plots and tabulations with one-millisecond resolution. A more detailed description of related Data Acquisition Programs is available.

TELEMETRY OUTPUTS

The SDS-930 outputs consist of a permanent storage file for the engineering units data on IBM 729 II and IV compatible digital tapes and a complete line printer tabulation of the data in engineering units as a function of time. In addition to the above, the data is plotted and tabulated in the form of 35mm film and hardcopy utilizing the Stromberg-Carlson Film Plotter (SC 4020).

CONCLUSIONS

The Telemetry Data System proves beneficial for recording data from such long duration tests (i.e., a test that lasts longer than several seconds). The transmitter requires little setup and the DHS receivers and computers require only 15 minutes lead time. The data can be rapidly reduced, converted to engineering units and displayed for analysis. Additional programming could enable complete data analysis and evaluation along with a finalized data presentation to be accomplished in a short turnaround time.

HARDWIRE TRANSIENT DATA SYSTEM (FIGURE 4)

Recording transient signals with magnetic tape or paper strip chart machines involves a considerable expenditure in material and equipment. Very short duration transients are even more difficult to record because they tax the abilities of these machines in the area of frequency response. In order to

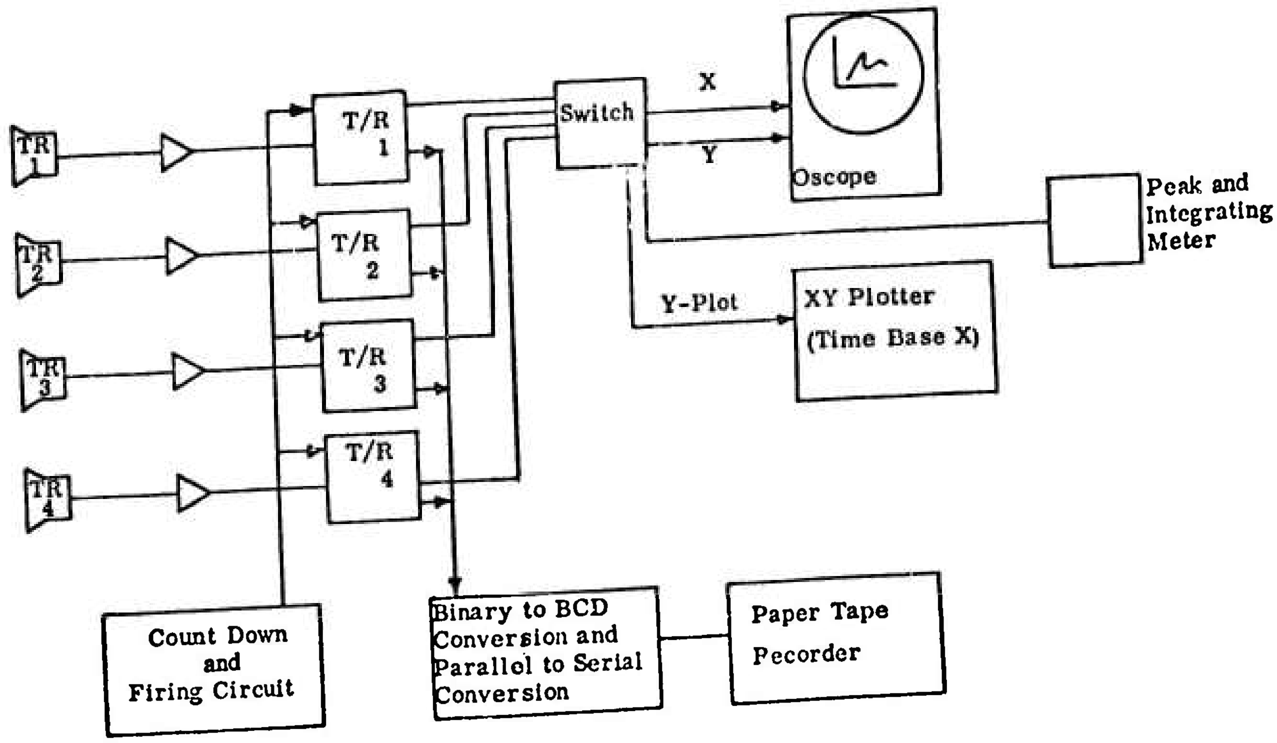


FIGURE 4. HARDWIRE TRANSIENT DATA SYSTEM

accommodate requirements for high frequency response, oscilloscopes are commonly employed. The "recording window" is, however, limited and data retrieval methods are limited to photographic methods.

GE-MTSD-MTR has recently begun an instrumentation program which is intended to combine the excellent electronic capabilities of the oscilloscope with the ease of data handling available in digital acquisition systems. Such a system is outlined in the following paragraphs.

TRANSIENT RECORDER

A Biomation Digital Transient Recorder, Model 610, stores a fast, one-shot signal for viewing on any scope or chart recorder and for digital output to a SDS-930 computer via a paper tape interface. This equipment, by means of analog to digital conversion and storage in a solid state memory, plays the part of an oscilloscope.

Features

The Transient Recorder is a new and basic tool for the electronic measurement of transient electrical signals. It is a simple, low cost instrument that was made specifically for the purpose of recording single events or low repetition rate signals and presenting these signals for continuous CRT display and plotter records. In addition, the instrument maintains the signal history as a series of digital numbers, and these digital outputs are available for external use in a computer or other digital recorder. Features include:

- MOS solid state memory
- 128 six bit digital words

- Differential inputs; range 50 mV to 50 V full scale
- Sweep time of 10 sec to 5.0 sec
- Input impedance compatible with oscilloscope probes
- Frequency response of DC to 1 MHz
- Analog output for oscilloscopes, X-Y or strip chart recorders
- Buffered digital output for computer interface or digital recorders
- Record single short transients or recurring signals
- Record signals starting before or after trigger is received
- Digital output smoothing

Output Displays

Readout of the transient recorder may be accomplished in two analog modes for quick look presentation of the data. The stored digital information can be output on command and displayed on the following equipment:

- Oscilloscopes can be used for X-Y presentation in the normal Y-time (triggered) mode of operation.
- X-Y recorders can be utilized for slowed down plots.
- SDS-930 computers interfaced via paper tape utilize the transient recorder to gather and hold input information; thus enabling all the SDS-930 peripherals to be utilized.

DHS REDUCTION AND PROCESSING

The SDS-930, as described in the DHS, is utilized in batch mode for data reduction and processing of the transient data stored on paper tape. Engineering Units Data is permanently stored on a master file and is presented in the

form of line printer tabulations and SC 4020 annotated plots and alphanumeric tabulations on 35mm film and hardcopy paper.

HAZARDS CLASSIFICATION AND EVALUATION PROGRAM

The GE-MTSD-MTR project involves detonating pyrotechnic samples to determine the peak pressures, time duration, and impulse from which additional phenomena can be calculated to determine hazards classification and evaluation. More information on this program is contained in GE-MTSD-MTR's "Pyrotechnic Hazards Classification and Evaluation Program", Phase I Final Report, Contract NAS8-23524, May 1970.

TNT EQUIVALENCY ANALYSIS

TNT Equivalency is defined as the energy released (determined by the blast pressures and impulses) from the detonation or explosion of a test material in terms of the amount of TNT which would release the same amount of energy when exploded. It is important to note that the pyrotechnic mixtures tested do not detonate but burn; however, under total confinement the test mixtures burst the sample container yielding an energy release which creates a time-pressure profile similar to that generated by a detonation of TNT.

Data collected during the TNT Equivalency test program was analyzed in three basic phases. In the first phase, mathematical techniques were applied to obtain a relationship between the pyrotechnic materials tested and TNT, by computing percent TNT equivalency values based on side-on peak overpressure and side-on positive impulse for each pyrotechnic material tested. The second phase utilized basic statistical procedures for organizing, summarizing, presenting, and analyzing data, as well as drawing valid conclusions

and making reasonable decisions on the basis of such analyses. The third phase was the engineering analysis of the TNT equivalent values from which general observations and conclusions evolved.

DATA REDUCTION AND ANALYSIS

The computer software is an integrated multiple program system capable of sequentially handling large quantities of experimental data to automatically generate fully correlated data presentations. A key feature is the capability to generate extensive and many varied plots and crossplots of data utilizing the SC 4020 hardware/software. Multivariate interpolation features are salient concepts to the manipulative processes of the system.

STATISTICAL ANALYSIS

Statistical techniques are utilized to obtain, analyze and present the digital data. The statistical elements utilized include:

- The collection and assembling of data
- Classification and condensation of data
- Presentation of data in a textular, tabular, and graphic form
- Analysis of data

Regression analysis techniques resulted in a least square polynomoal in ln Z (scaled distance) being applied to the data for the best fit curve.

CONCLUSIONS AND RECOMMENDATIONS

It is believed that the two data systems (Telemetry and Transient) have advanced the current state-of-the-art in the areas of instrumentation,

succeeded by the acquisition, reduction, analysis and display of data required to support the hazards testing of pyrotechnic and explosive materials. The systems are currently undergoing modifications which greatly increase the engineering and/or data analysis capabilities.

In addition to the Telemetry and Transient Data System, there exists several other applications where the current state-of-the-art can be advanced by applying the systems approach. Several recommended applications are:

- A complete systems analysis of the current hazards evaluation program by looking at the overall situation rather than the narrow implications of the task at hand; particularly, looking for inter-relationships between the task at hand and the other functions which relate to it.

- A hazards data retrieval system which will consist of the network of all communication and/or data processing methods available within an organization for cataloging vast amounts of data (all related to a particular field of interest) so that the information can be filed, stored, located, and displayed (via applicable peripheral equipment).

INSTRUMENTATION TECHNIQUES FOR PYROTECHNIC TESTING

William H. Rehmann

General Electric Company
Management and Technical Services Department

Testing of pyrotechnic and explosive materials require a diversity of instrumentation unlike other testing situations. Where is no "steadystate" data. The data to be recorded occurs one time for a short period and may even occur unexpectedly. This kind of response is typical of high and low order detonations. On the other hand burning tests create a very low response situation yielding data of a few cycle per second bandwidth. Finally, both responses may be required in the event of a runup reaction where burning becomes deflagration and detonation follows.

As in any form of testing, a measurement philosophy must be developed in which the balance is struck between a few highly instrumented tests and many tests with simple measurement requirements. As is usually the case, economics plays the largest role in determining this point of balance.

The Materiel Testing and Research subsection has been using piezoelectric pressure transducers, charge amplifiers, oscilloscopes and Polaroid cameras for the acquisition of high speed transient data. For medium to slow speed acquisition, a standard IRIG telemetry system is employed. The output of the telemetry receiver is handled by a SDS-930 computer. Figure 1 depicts, in block diagram, the functioning of the telemetry system. This mode of data acquisition is very advantageous because it lends itself to minimum setup time, minimum equipment at the test site, maximum flexibility of input sensors and a rapid turn around time in the data reduction due to the use of the computer and its peripheral equipment.

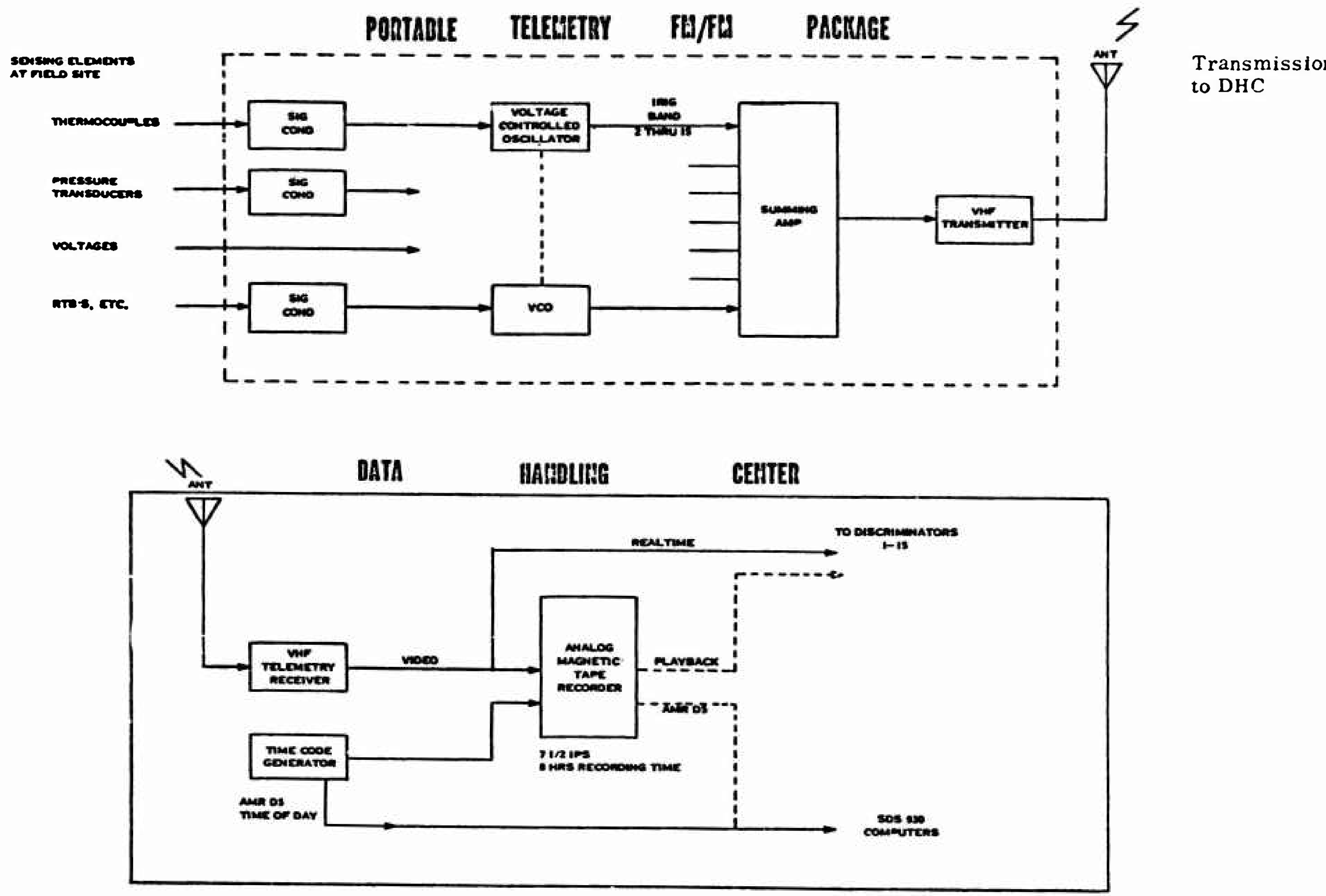


Figure 1. Remote-Telemetry-Control Acquisition System

The use of oscilloscopes for the recording of high speed transients is a very common but not altogether satisfactory technique. The trouble lies not in the electronic aspects of the circuitry but in the limited format in which the data is presented. Specifically, oscilloscope phosphors are either to "slow" to catch the writing speed of the electron beam or they are to "fast" to prevent blurring of the quiescent portions of the trace. Finally the scope presentation does not lend itself to any data reduction techniques other than photographic. These photographs may be treated manually or on relatively expensive telereading equipment.

Magnetic tape recording equipment has been used by some testing groups but it is also expensive if satisfactory bandwidth capabilities are employed.

Materiel Testing and Research subsection has recently begun an instrumentation program which is intended to combine the excellent electronic capabilities of the oscilloscope with the ease of data handling available in digital acquisition systems. Such a system is outlined in Figure 2. The heart of this equipment is a digital transient recorder built by Biomation Incorporated of Palo Alto, California. This remarkable new unit has the controls and input features of an oscilloscope. However, the signals are digitized and stored in an MOS solid state memory. This memory holds 128 six-bit digital words. Readout of the transient recorder may be accomplished in two analog modes for quick look presentation of the data. One mode is suitable for X-Y chart or timebase X-Y recorders. Finally the digital memory may be interrogated in terms of the individual digital words for digital data reduction by computer.

Looking at the overall picture, the countdown and firing circuits initiate a transient phenomena and may be used to trigger the recorders. Transducers

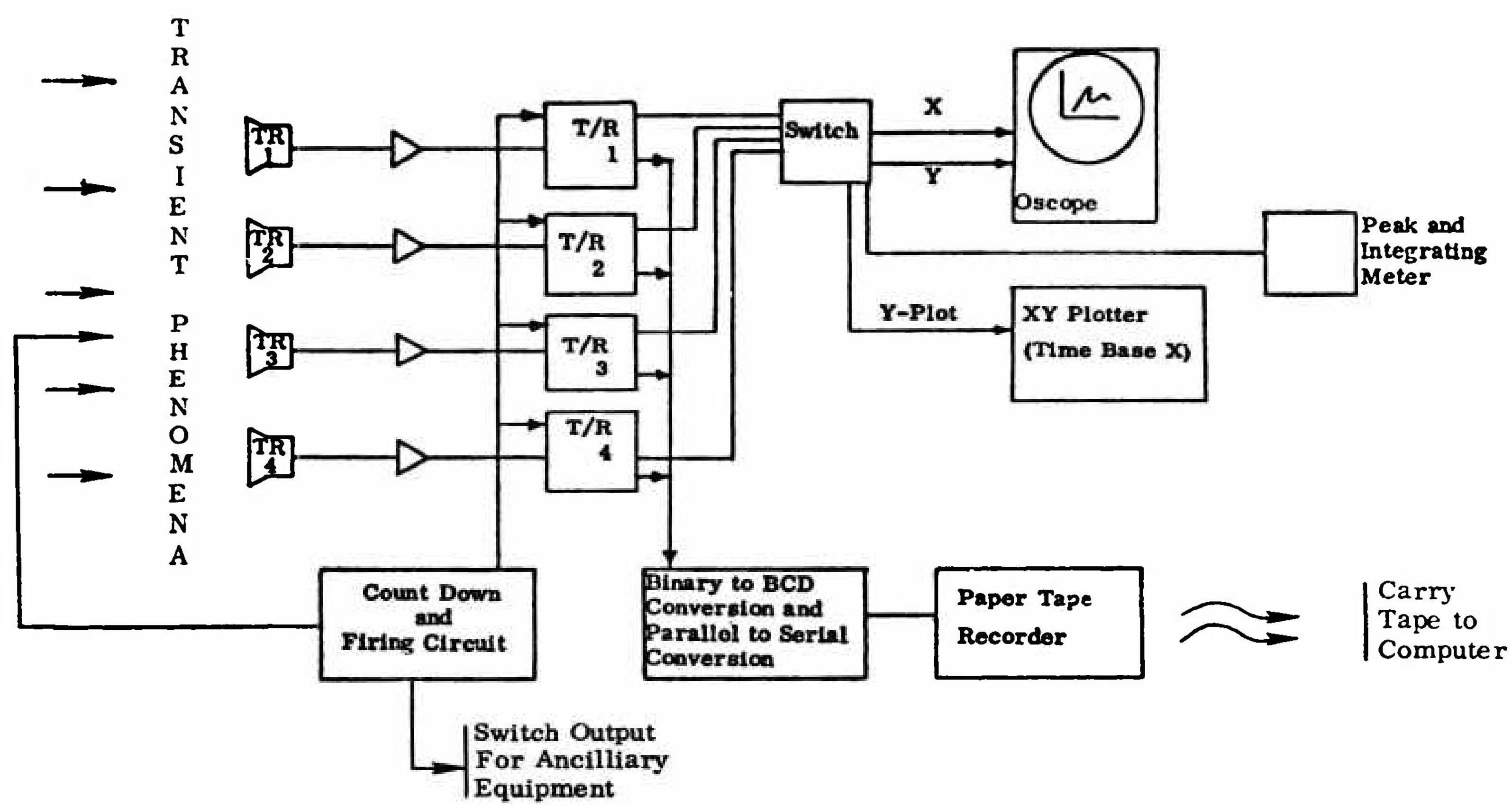


Figure 2. Transient Data System Showing Paper Tape Interface

measure some parameter of the transient and after amplification it records one of the Biomation recorders. The measurements are now in memory and will be retained there until a new trigger is delivered.

A simple switching circuit permits visual presentation on a sequential basis of each recorder memory on the X-Y oscilloscope or in the timebase X-Y plotter. In the future a peak and integrating voltmeter will be installed to present peak over pressure and impulse data directly.

Finally each recorders memory will be interrogated and its contents transferred via the conversion equipment to a punched paper tape. This paper tape will then be reduced by the 930 computer at the Data Handling Center.

BLANK PAGE

EDGEWOOD ARSENAL PYROTECHNIC HAZARDS EVALUATION AND CLASSIFICATION PROGRAM - PHASE I

D. M. Koger, Program Manager
General Electric Company
Management and Technical Services Department

Described in this report are the abstract, conclusions and recommendations of the Phase I Edgewood Arsenal's three-phase Pyrotechnics Hazards Evaluation and Classification Program. The Phase I program was conducted by the General Electric Company, Management and Technical Services Department (GE-MTSD), Bay Saint Louis, Mississippi, under National Aeronautics and Space Administration (NASA) Contract NAS8-23524 for the Engineering Test and Evaluation Section, Process Technology Branch, Chemical Process Laboratory, Weapons Development and Engineering Laboratory, Edgewood Arsenal, Edgewood, Maryland.

An experimental investigation was conducted to determine the potential hazards associated with pyrotechnic compounds, both in the bulk granular state and the finished end item configuration. Potential hazards were defined by two basic criteria: U. S. Army Technical Bulletin 700-2 (TB 700-2) classification, and TNT Equivalency or energy release characteristics relative to the energy release characteristics of TNT. This program, entitled Phase I, was thus divided into two segments of work: Segment 1, which entailed TB 700-2 classification; and Segment 2, which provided for TNT Equivalency classification and evaluation.

During Segment 1, eleven bulk pyrotechnic smoke compounds and seven bulk pyrotechnic starter compounds were subjected to TB 700-2 tests. Seven smoke compounds and two starter mixes met the criteria for a probable Class 7 classification. The probable Class 7 classifications were based on paragraph 3-13 of TB 700-2 which states that a material is Class 7 if an impact sensitivity test produces an explosion above four inches of drop height.

Detonation was not experienced in any of the three tests to which the six end items were subjected. Five smoke grenade items tested showed no item-to-item or case-to-case propagation. Propagation was experienced between the 105mm HC smoke canisters only.

Segment 2 tests resulted in TNT Equivalency values for ten of the eleven bulk smoke samples in a range from 3.72 percent to 10.88 percent. The bulk HC sample failed all attempts to produce a detonation-type reaction; i.e., a measurable blast overpressure and impulse.

Two general conclusions were drawn from these tests:

a. The required test for classifying hazardous materials in the U. S. Army Technical Bulletin 700-2, "Explosive Hazards Classification Procedures", does not provide for an adequate classification of pyrotechnics.

b. A meaningful criteria with respect to energy release and damage potential may be established by TNT Equivalency testing or damage index of pyrotechnics compounds in a 100 percent confining container.

Therefore, it is recommended that action be initiated to provide a separate and distinct specification for pyrotechnics testing to include TNT Equivalency or damage index test procedures and criteria which will result in an adequate classification of pyrotechnics.

GENERAL

All of the TB 700-2 tests were obviously designed for materials generally classified as explosive or high explosive materials. Pyrotechnics, which are basically designed to burn under various conditions at various rates, certainly cannot be expected to react to the stimuli specified by TB 700-2 in a manner providing conclusive data on a "go-no-go" test. Nor would they be expected to react "go-no-go" as a typical high explosive.

A more meaningful criteria by which to classify and/or evaluate a pyrotechnic material is by determining the degree of sensitivity, the hazard or damage potential, and the tendency of the material to transition from ignition to deflagration to detonation. In the following specific conclusions, each of the Segment 1 and Segment 2 tests and test methods will be examined with respect to these determinations.

DETONATION TEST

All testing to date confirms the desirability of appropriate revisions of TB 700-2 for application to pyrotechnic compounds. For example, the Standard Detonation Test does not lend itself to meaningful testing and evaluation of granular materials. Additionally, the testing procedure does not provide for containment of the granular sample nor for standard compression, tamping, or confinement of the material. During the test program, laboratory filter paper was used to construct a cube shaped box to hold the required 2-inch cube sample.

It was found that in the case of pyrotechnic materials, mushrooming of the lead cylinder did not occur. If it had occurred, there was no provision in TB 700-2 to describe whether the "mushrooming" was 1/16 inches or 2 inches, etc. In an effort to detect any minute distortions in the lead cylinders, a "go-no-go" gage with 1/16 inch clearance was constructed to check for "mushrooming".

To answer the question as to whether the sample "fragmented", it was found necessary to supply a footnote to Form AG0793/A to explain that the action of the blasting cap "scattered" rather than fragmenting the sample material.

IGNITION AND UNCONFINED BURNING TEST

The observed effects of minimal scattering and complete burning of the sample material indicates only that the pyrotechnic material performs the function it is generally intended to perform, i.e., burn at a designed rate. Any other use of the test is inconclusive since TB 700-2 does not contain criteria or requirements for the burning rate; therefore, there is no apparent relationship between burning rate and classification.

Again the problem exists in the preparation of a typical granular sample for testing using the 2-inch cube criteria. The specification should provide for granular bulk samples as well as consolidated samples. It is apparent that the specification is written for a typical high explosive or propellant which is generally a solid material that can be cut or machined into the required 2-inch cube.

THERMAL STABILITY TEST

It is difficult to ascertain from the small number of pyrotechnic materials that were subjected to the thermal stability test whether or not the test provides conclusive data with respect to these materials. The only positive results obtained from the 11 smoke sample compounds and seven starter mixes was a "change in configuration" in the HC smoke mix and Starter Mix V caused by a loss in volatile chemicals. The change was actually a change in weight and a slight reduction in the size of the sample.

Although the sample cube was provided with a thermocouple, no unusual temperature deviations were observed on the strip chart recorder data sheets. Dual thermocouple should be imperative for any type of material where an exothermic or endothermic reaction might be expected to occur.

IMPACT SENSITIVITY TEST

The conclusions derived during this test program relative to the impact sensitivity test were made with respect to the factors of blending, screening, and mixing of the samples as a primary consideration. The size of sample and the capability to duplicate the identical mixture of a particular sample during the test sequence is unpredictable and warrants further examination. It is safe to assume that the probability of drawing a sample representative of the total mix or lot (bulk) each time a 10 milligram sample is taken is infinitesimally low. Increasing the size of the sample tested may increase the validity of the results.

Statistically the results taken from a 20 test drop sampling are inconclusive. The population (quantity) of tests should be increased to permit better statistical correlation. It would also be advisable to examine this test in terms of degree of sensitivity by performing the test drop at an increasing height until detonation is exhibited or a maximum limit is reached. Computation could then be oriented to a degree of sensitivity.

CARD GAP TEST

GENERAL

The card gap test, by observation of test results performed on pyrotechnics, is another in the series of "go-no-go" tests characteristic of the TB 700-2 specification. The violent reaction of the two pentolite pellets, as demonstrated by the fragmentation of the card gap tube and the hole punched in the witness plate (when fired independent of any sample material), makes measurement of any reaction less than a detonation by the donor sample difficult. The fact that the witness plate is only deformed in the pyrotechnic tests tends to confirm the relative stability of the pyrotechnic and would indicate an attenuation of the pentolite reaction. The difficulty in relating deformation of the witness plate to other factors, such as TNT equivalency, is further proof of

the relative stability of the samples. The slight variance in the recorded overpressure and impulse data from the instrumented card gap tests when compared to the open air bursts of pentolite indicates that there is little additive reaction from the sample to the pentolite.

The "go-no-go" characteristics of the card gap test warrants further examination with respect to its use as a means of determining degree of sensitivity. When testing high explosives, the introduction of cellulose acetate cards between the sample and the pentolite does offer a sensitivity range computation capability. Without detonation, as occurs with the types of pyrotechnics tested in this program, the sensitivity measurement is not possible.

WITNESS PLATE MATERIAL

After performing the special tests with the different witness plate materials, it must be concluded that the specification requirements with regard to the steel plate must be more explicitly defined. If, in fact a witness plate can shatter and void a test; a witness plate could also fail to produce valid "go-no-go" results due to variations in the properties of the steel within the specification.

WITNESS PLATE VOLUMETRIC AND DEFORMATION MEASUREMENT

Based on the relatively limited potential energy range of materials tested, the work performed in linear and volumetric measurement of card gap witness plate deformation was rather inconclusive. An effort to correlate deformation data with TNT equivalency with little or no conclusions obtained. Until more exact measurement techniques are employed, such as burning rate probes and pressure transducers inside the pipe, the slight variations in energy release in the card gap configuration will be difficult to determine.

ORIENTATION

Card gap tests were fired in a 90° and 180° orientation from that specified by TB 700-2 to determine primarily the efforts on the blast pressure data. It was determined that the overpressure distortions caused by the previously discussed asymmetric rupturing of the sample pipe were only exaggerated by reorientation. It was also found that the inverted or the horizontal card gap test setup only resulted in difficult recovery of the witness plate. An additional hazard is also introduced into the test program caused by a large size fragment in the form of the witness plate.

INERT SAMPLE TESTS

Card gap tests run with an empty sample tube and the normal configuration showed greater plate distortion than any of the pyrotechnic samples tested. Conversely, ordinary sand tested in the card gap configuration exhibited little or no distortion of the plate. It can be concluded from these results that the pyrotechnic material only serves to attenuate the blast pressure wave front. The denser the material the greater degree of attentuation that is experienced.

TNT EQUIVALENCY

The proof of any pyrotechnics compound's "damage potential" lies in its capability to cause destruction by means of explosion or fire. Since the pyrotechnics tested were not intended to explode, but were designed to burn at a prescribed rate, it is apparent that a test is warranted that would intentionally cause the sample to detonate, thereby providing a basis for measuring the damage potential and the tendency of the material to communicate from ignition to deflagration to detonation. The TNT equivalency test developed and reported in this document tends to satisfy the "damage potential" requirement.

The tests performed in Segment 2 of Phase I of this program must only be taken as a beginning in this area of pyrotechnic testing. The TNT equivalency values derived from the overpressures and impulses recorded for various materials must be suspected as being on the low side. There are a number of factors which caused these values to be lower than that which was originally expected. Some of these reasons are:

- Nonuniform rupturing of the pipe containing the sample caused a corresponding nonuniform shock front. This phenomena in turn created a situation in which much of the energy released during the explosion reaction was not "seen" (sensed) by the pressure transducer.
- It appeared from the high speed films of the TNT equivalency tests that incomplete combustion occurred inside the test cylinder. The films showed colored smoke resulting from the explosion rather than the black smoke that should occur if all of the hydrocarbons were reduced to their basic chemical constituents.
- Much of the energy released by the explosion was disipated in energy required to rupture the pipe. In future TNT equivalency tests to be conducted in Phase III of the program, attention will be directed toward correcting the factors which may have detracted from the adequacy of data. Some of the areas of investigation are discussed in Section 5, Recommendations.

END ITEM TESTS

DETONATION TESTS A AND B

The primary conclusion which was derived from end items tests (Detonation Tests) A and B was that the packing materials employed in end item containers contributed significantly to the inhibiting of propagation within a container as well as container to container. This conclusion is based on the results of the five M-18 smoke grenade end item tests where each of the M-18 grenades are individually packaged in cardboard containers. These containers served to prevent propagation within the container from one item to another. The HC canisters, which are not individually packaged, showed total propagation in all A and B tests.

To provide significant data for evaluation by ASESB or the testing agency, GE-MTSD instrumented all end item tests for blast overpressure and impulse. Additionally, an optical pyrometer was utilized for flame temperature readings.

It appeared from film records and observations in HC canister tests that mass contributed significantly to the rate of reaction; i. e., there may be an exponential increase in burning rate as the mass of the sample materials increases.

END ITEM TEST C (EXTERNAL HEAT TEST)

As stated in the discussion on Tests A and B, the Test C TB 700-2 specification did not require blast instrumentation or thermal measurements. However, it is felt that data which would result from this instrumentation would provide significant data relative to mass, geometric configuration, and synergistic effects.

RECOMMENDATIONS

GENERAL

Based on the conclusions expressed previously, literature search material, Phase I test data, and observations and evaluations by GE-MTSD and Edgewood Arsenal personnel, many definite recommendations can be made.

A summary of the recommendations based solely on the Phase I work is as follows:

a. Revise TB 700-2 to accommodate tests appropriate for pyrotechnics (more definitive recommendations in regard to new tests, test methods and procedures will be derived from Phase III testing.

b. As the damage/hazard potential of pyrotechnics and pyrotechnic raw materials can be defined in terms of TNT equivalency, Phase II testing should be directed to determination of those stimuli, confinements, environments, and other physical and chemical variables which can create haz ırds and potentially hazardous conditions in pyrotechnic operations, transportation and storage.

DETONATION TEST

The following recommendations are offered with respect to the TB 700-2 Detonation Test:

a. This test should be deleted as a requirement for pyrotechnics classification, since it has been demonstrated that pyrotechnics are not susceptible to detonation in the unconfined state.

b. The test procedure as applied to other materials should specify the method of containment for bulk materials, as well as a requirement for consolidation of these materials if the material is consolidated as an end item.

c. A specific definition of "mushrooming of the lead cylinder" must be included in the specification. Additionally, the definition of "fragmented" must be more explicit for bulk or loose materials.

IGNITION AND UNCONFINED BURNING TEST

The following recommendations are offered with respect to the TB 700-2 Ignition and Unconfined Burning Test:

a. This test should be deleted as a requirement for pyrotechnics since this does not provide a definitive enough basis for determining burning rate. Additionally, the chance of detonation of the pyrotechnic is extremely remote as tests have shown that these materials are not susceptible to a detonation reaction.

b. Explicit specifications should be called out for the kerosene and sawdust materials used in this test for other materials. Consideration should be given to using alcohol as the flame supporting medium.

c. As stated previously relative to the Detonation Test, confinement and configuration should be more specifically defined for bulk, loose materials.

THERMAL STABILITY

The following recommendations are made relative to the TB 700-2 Thermal Stability Test:

a. Consideration should be given to requiring a thermocouple in the sample cube to record possible temperature deviations as a function of time. The thermocouple and recorder would also provide a means of determining the point in time and temperature when an explosion or fire occurred.

b. Consideration must be given to utilizing differential thermal analysis (DTA) and thermogravimetric analysis (TGA) for sensitivity/classification determinations of pyrotechnics. These laboratory techniques provide greater accuracy and control than the present system.

c. The definition of a "change in configuration" should be more clearly defined in TB 700-2.

d. In lieu of a DTA or TGA type test, a thermal stability test should be considered which would provide data as to what magnitude of thermal environment the material could endure without explosion, detonation, or burning; i.e., an autoignition type test would provide more meaningful, usable data than a simple "go-no-go" constant temperature test.

e. Comments made previously with regard to configuration and confinement of the sample also apply to the Thermal Stability Test.

IMPACT SENSITIVITY TEST

The following recommendations are made relative to the TB 700-2 Impact Sensitivity Test:

a. The specified sample size should be increased. The existing TB 700-2 specified sample size (10 mg) precludes an assurance that a representative sample will be drawn with any significant degree of probability. For many pyrotechnic materials, a few granules of a single constituent may weigh the required 10 mgs. If the few granules are the more sensitive of the constituents, the sample material may detonate. A single detonation induced by the factors described above can cause the material to be classified Military Class 7 instead of Class 2. Increasing sample size could provide a positive statistical factor in assuring that a representative sample is selected.

b. An increase in the number of samples run on each compound would provide a greater statistical probability that the reaction occurring represents to some degree the reaction that you would expect from the whole.

c. TB 700-2 should call out procedure methods and standards for blending or reblending samples to be tested, particle size requirements for the sample, and special preparation provisions for certain types and classes of materials.

d. There should be some investigation into the merits of using the Bureau of Explosives impact apparatus as an entirely different concept may be required for pyrotechnics.

e. If impact tests are to be a requirement for classification testing of pyrotechnics, some consideration should be given to testing the materials at varying weights and/or heights until a positive reaction of some kind occurs.

f. Because of the relative importance of temperature to the test environment, test equipment and materials, TB 700-2 temperature control requirements should be tightened. Additionally, conditions of humidity must also be specified in order to provide valid, reliable and accurate test data.

g. For any impact test, there must be a more clearly defined method for stabilizing the apparatus. It is very probable that the impact test results could be biased by the method that was employed to restrain or cushion the apparatus.

h. Increasing sample weight or providing instrumentation to detect the reaction should be investigated as difficulty was often experienced while running impact sensitivity tests in either hearing or seeing the reaction that occurred. This was usually true on a marginal test and might require a rerun of the sample to confirm the reaction.

CARD GAP TEST

For the Card Gap Test to be effective, sympathetic detonation must occur in the acceptor material, but pyrotechnics have shown no indication of this. Therefore, because the Card Gap Test does not provide a valid means of classifying or measuring the sensitivity of a pyrotechnic material, it is recommended with respect to the Card Gap Test as specified by TB 700-2 that, for materials that could meet the sympathetic detonation criteria, the Card Gap Test procedure be more clearly defined with respect to: (1) witness plate materials - too hard or brittle a plate could bias the test by shattering rather than having a hole punched in the plate; (2) witness plate stand configuration - the stand is specified as being required to support the plate on two edges, whereas the picture in the specification (TB 700-2) shows a stand which supports the plate at four corners.

TNT EQUIVALENCY

The TNT equivalency test as performed by GE-MTSD is not conclusive with respect to providing exact data with respect to the number of pounds of the pyrotechnic that are equivalent to some quantity of TNT. However, the TNT equivalency test proved conclusively that:

a. Pyrotechnics can be made to detonate if properly confined and initiated by the proper stimuli.

b. Pyrotechnics have a "damage potential" which can be measured in terms of blast overpressure, impulse, and fragmentation.

With respect to the TNT equivalency test it is recommended that:

a. The TNT equivalency test be included as one of the TB 700-2 type sensitivity/classification tests. The test would necessarily have to be refined, modified, and checked out.

b. The TNT equivalency test should be thoroughly investigated and a technically acceptable test be specified which will provide for reliability, reproducibility, and accuracy over a wide range of "Z" (lambda) values.

c. Pressure and burning rate probes be installed as part of the test investigation conducted in b above.

END ITEM TESTS

The following recommendations are made with respect to the End Item Tests A, B, and C in TB 700-2:

a. The test procedure should require additional instrumentation to the extent that blast overpressure and impulse can be recorded for all pyrotechnics and item tests.

b. The procedure should also require instrumentation for recording of temperatures during all of the pyrotechnic end item tests.

c. To record the significant test events such as explosion and subsequent fragment dispersion, it would be judicious to require color motion picture coverage for end item tests. Camera speeds in the neighborhood of 500-3000 frames per second are recommended for this application.

d. Although it may be beyond the scope of TB 700-2 testing, consideration must be given to packaging and packaging methods employed for pyrotechnic end items. The results of the end item tests discussed previously indicate that flame attentuation is possible for pyrotechnics.

EFFECTS OF COPPER AND HEAVY METALS ON SENSITIVITY OF PYROTECHNIC MATERIALS

J. F. Pankow
General Electric Company
Management and Technical Services Department

Concern about the use of copper and copper alloy tools and equipment in the production processes for pyrotechnic mixes containing potassium chlorate ($KClO_3$) resulted from experimentation where an aqueous solution of potassium chlorate was doped with crystalline copper chlorate and ground with sulfur. The resultant mixture spontaneously combusted. This experimentation led to the recommendation that copper and copper alloy tools and screens be removed from $KClO_3$ operations as a safety measure.

The objectives of this study were to investigate, test, and evaluate the effects of the addition of copper chlorate and other heavy metal salts on the sensitivity of $KClO_3$-S and $KClO_3$-S based pyrotechnic compositions. More than twenty-five references were surveyed to determine that production environments were not conductive to the formation of copper chlorate.

Laboratory chemical analysis of the raw materials, bulk compounds and end items associated with this study indicated trace quantities of copper in all materials except raw sulfur. Laboratory differential thermal analyses were performed and indicated an increase in the copper and heavy metal salts but a decrease in sensitivity with increased quantities of raw copper, iron and their oxides.

Field testing of the materials and the contaminants by means of a specially designed test method enabled computation of a TNT Equivalency value. Results of these tests showed a marked decrease of sensitivity in the pyrotechnic material with the addition of copper and iron contaminents.

Based on this study it is recommended that copper and copper tools and screens remain in pyrotechnics production plants because neither the oxidation products of copper nor copper itself causes a significant increase in the sensitivity of $KClO_3$-S mixes nor is it conceivable that any of the contaminants causing increased sensitivity will be formed in the production process.

BACKGROUND

Concern about the use of copper and copper alloy tools and equipment in the production processes for pyrotechnic mixes containing potassium chlorate and potassium chlorate-sulfur resulted from the findings reported by Washington College under Contract DA-AMC-18-035077F and resultant reports Nos. WCDC 6465 and 6667. These reports conclude, based on experimentation where an aqueous solution of potassium chlorate was doped with crystalline copper chlorate and ground with sulfur, that the presence of copper ions in potassium chlorate-sulfur mixes greatly increases the sensitivity of such products. This conclusion led to the recommendation that copper and copper alloy tools and screens be removed from $KClO_3$ operations as a safety measure.

OBJECTIVES

The major objectives of this study were to investigate, test, and evaluate the effects of the addition of copper chlorate and other heavy metal salts (as contaminants) on the sensitivity of potassium chlorate-sulfur and potassium chlorate-sulfur based pyrotechnic compositions.

COPPER CHLORATE ($Cu(ClO_3)_2 \cdot 6H_2O$) PRODUCTION

To produce copper chlorate either on a laboratory basis or on a production plant basis, the following definite controlled conditions must exist:

- Copper must be taken into solution with a strong acid such as nitric (HNO_3) or sulfuric (H_2SO_4) to form cupric nitrate ($Cu(NO_3)_2 \cdot 3H_2O$) or cupric sulfate ($CuSO_4 \cdot 5H_2O$).
- An alkali such as sodium hydroxide (NaOH), potassium hydroxide (KOH), or ammonium hydroxide (NH_4OH) must be introduced into the solution containing the copper salt to produce cupric hydroxide ($Cu(OH)_2$).
- Chlorine must be passed through a hot cupric hydroxide slurry in the presence of an oxygen rich atmosphere for several hours to finally produce copper chlorate ($Cu(ClO_3)_2 \cdot 6H_2O$).

More than twenty-five references were surveyed to determine that the above conditions must exist before copper chlorate could be formed. No other method for the production of copper chlorate was found in the surveyed literature.

LABORATORY CHEMICAL ANALYSIS

Quantitative chemical analysis of the raw materials, bulk compounds, dyes, starter mixes and end items for the concentrations of suspect contaminants of copper and other heavy metals, was carried out utilizing atomic absorption spectrophotometric analysis.

Concentration of copper and iron impurities is shown in Table 1.

LABORATORY DIFFERENTIAL THERMAL ANALYSIS

Sensitivity of the potassium chlorate-sulfur mixes and the M-18 Sulfur Red was further examined in the laboratory using a Fischer Series 200 Differential Thermal Analysis (DTA) apparatus.

Table 1. Copper and Iron Impurity Range

MATERIALS	PERCENTAGE	
	COPPER	IRON
Raw Materials	0-.012	0-.436
Bulk Compounds	0-.015	0-.104
End Items	0-.006	.002-.049
Starter Mixes	.005-.038	.018-.036
Dyes	0-.077	.019-.047
$KClO_3$	.0012	0
Sulfur	0	0

DTA measurements are used extensively to detect any exothermic or endothermic changes that might occur in a chemical system by measuring the temperature difference between a sample and a thermally inert reference material. When a temperature difference is plotted as a function of increasing temperature, a curve known as a thermogram is produced. A typical recorder tract (thermogram) is shown in Figure 1.

IMPACT SENSITIVITY

Sensitivity of the $KClO_3$-S mix and a selected $KClO_3$-S based pyrotechnic (M-18 Sulfur Red) was examined using the Impact Sensitivity tests as defined in the U. S. Army Technical Bulletin 700-2, "Explosives Hazards Classification Procedure".

It was observed that the sensitivity of the $KClO_3$-S was such that further use of this test would be inconclusive. The test did, however, provide some insight into the change of sensitivity on a $KClO_3$-S based pyrotechnic composition.

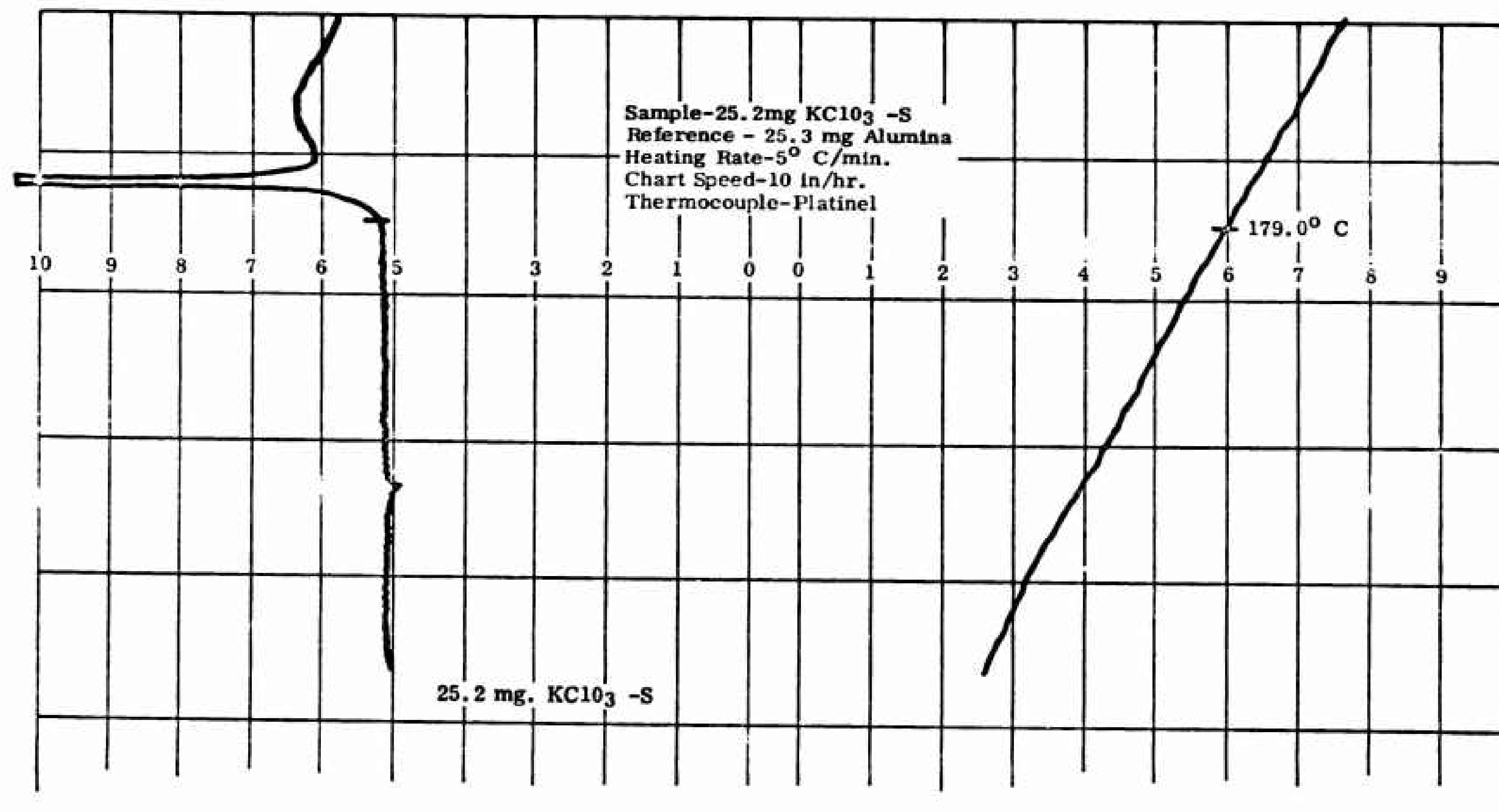


Figure 1. Differential Thermal Analysis Thermogram, Typical

As the concentration of copper chlorate in the Sulfur Red compound increased, the number of decomposition indications also increased.

BLENDING AND MIXING

The blending and testing of the effects of copper chlorate on $KClO_3$ and S were performed in three separate and distinct processes:

- Dried crystalline copper chlorate was blended with $KClO_3$ and sulfur in a special blending apparatus and stored at room temperature.

- Copper chlorate and $KClO_3$ were prepared in an aqueous solution, dried, blended with sulfur by grinding with a mortar and pestle, and stored at room temperature.

- Copper chlorate and $KClO_3$ were prepared as above and subjected to a humidity of 60 percent for three days before being blended with sulfur by grinding with a mortar and pestle, and stored at room temperature.

In each process, the concentrations of copper chlorate were retained at 1.0, 5.0, 10.0, 17.5, and 25.0 percent.

Results of blending are shown in Tables 2 through 5.

ORDER OF SENSITIVITY

Testing of select pyrotechnic production materials by means of a specially designed test method enabled computation of a TNT equivalency value.

Table 2. Dried Crystalline Copper Chlorate Mixed with $KClO_3$-S

CONCENTRATION	REACTION
1.0%	No reaction
5.0% 10.0% 17.5%	Spontaneously combusted after 26 days storage at 75°F in an explosion proof oven.
25.0%	Spontaneously combusted after 25 minutes in the oven.

Table 3. 25 Percent Dried Copper Chlorate Blending with $KClO_3$-S

RUN NO.	ATMOSPHERIC		OVEN TEMPERATURE	REACTION TIME
	TEMPERATURE	HUMIDITY		
1	80	55	75°	25 minutes
2	Unknown	Unknown	75°	46 hours 30 minutes
3	37	64	75°	2 hours 20 minutes
4	37	64	75°	2 hours 3 minutes
5	37	64	75°	35 minutes
6	Unknown	Unknown	75°	8-16 hours (during the night when unobserved

Table 4. Aqueous Copper Chlorate and Potassium Chlorate Blending with Sulfur - 0 Percent RH

SAMPLE	CONCENTRATION $Cu(ClO_3)_2 \cdot 6H_2O$	REACTION DURING BLENDING	REACTION DURING STORAGE (75°F)
1	1.0%	Popping noise noticed	No reaction
2	5.0%	No reaction	No reaction. Sample deteriorated to brownish crystals after 21 days in storage.
3	10.0%	No reaction	Spontaneous combustion 2 hours after blending
4	17.5%	Popping noise noticed	Spontaneous combustion 42 minutes after blending
5	25.0%	Violent reaction 2/3 of sample burned	Spontaneous combustion 48 minutes after blending

Table 5. Aqueous Copper Chlorate - Potassium Chlorate Blended with Sulfur - 60 Percent RH

CONCENTRATION $Cu(ClO_3)_2 \cdot 6H_2O$	REACTION RESULTS FROM BLENDING	DTA TEMPERATURE	LONG TERM STORAGE RESULTS
1.0%	No reaction	173.8°C	No change
5.0%	No reaction	148.3°C	No change
10.0%	No reaction	140.3°C	No change
17.5%	No reaction	90.0°C	No change
25.0%	No reaction	-	10 days - reacted

TNT Equivalency is defined as the amount of weight of pyrotechnic material to produce an explosion overpressure at a point equal to that caused by one pound of TNT.

Results of the testing are shown in Table 6.

SIGNIFICANT OBSERVATIONS OF ENVIRONMENT CONDUCIVE TO COPPER CHLORATE FORMATION

During the literature survey into conditions conducive to copper chlorate formation, it was found that copper chlorate could be formed during an electrolytic process. For the electrolytic reaction to proceed, the following electrolysis requirements must be met:

- A conductor or an electrolyte which will allow the mobility of electrons from one point to another must exist.
- A cathode and an anode must be present in some form before electrolytic action can proceed.

Table 6. TNT Equivalency

MATERIAL	IMPURITY COMPOUND	%	ENERGY RELEAST OVERPRESSURE	VALUE(%)
$KClO_3$-S	None	0	12.36	35.46
$KClO_3$-S	Cu	17.5	10.58	28.26
$KClO_3$-S	Fe	17.5	9.36	27.29
$KClO_3$-S	Fe_2O_3	5.0	8.51	20.47
$KClO_3$-S	Fe_2O_3	17.5	6.55	13.67
M-18SR	None	0	3.71	5.35
M-18SR	Fe_2O_3	5.0	2.00	1.39
SMVI	None	0	8.36	20.21

- o An electrical charge of some form must be present before electrolysis can exist.

By taking two probable cases prevalent in a production proceed and attempting to relate the situation to the potential for production of copper chlorate, the following would be observed:

- o Case 1 - a bad ground where electrolytic reaction between two dissimilar metals, such as copper and iron, causes buildup of reaction product.
  - Observation - in the presence of water, potassium hydroxides would be formed regenerating to potassium chlorate, causing a buildup of potassium chlorate to occur.
  - Potential to produce copper chlorate - none.
- o Case 2 - a buildup of products on a copper vessel or a vessel containing copper.
  - Observation - patina and/or verdigris, formed by corrosive action of copper, as either copper sulfate or copper chloride.
  - Potential to produce copper chlorate - none.

There are more accidental conditions which come to mind which would appear to permit development of copper chlorate; however, the conditions and/or changes in environment would themselves cause ignition of the pyrotechnic.

CONCLUSIONS

The following conclusions can be drawn from the results of this study:

- Copper chlorate ($Cu(ClO_3)_2 \cdot 6H_2O$) increases the sensitivity of potassium chlorate-sulfur and M-18SR mixtures.
- Copper chlorate causes spontaneous combustion when mixed with potassium chlorate-sulfur in concentrations of 5, 10, 17.5, and 25 percent at 0 percent relative humidity.
- Copper chlorate does not cause spontaneous combustion when mixed with M-18SR in concentrations of 1, 5, 10, 17.5, and 25 percent.
- Differential Thermal Analysis shows that copper and copper oxide have no profound effects upon the sensitivity of potassium chlorate-sulfur and M-18SR mixtures when mixed in concentrations of 1, 5, 10, 17.5, and 25 percent.
- Other metals such as nickel, chromium, and manganese do not increase the sensitivity of the potassium chlorate-sulfur mixture.
- Oxides of iron, chromium, cobalt, manganese and nickel do not cause large increases in sensitivity of the $KClO_3$-S mixture, but some sensitivity increase was observed by Differential Thermal Analysis for each metal oxide. The increase shown by iron oxide is so slight that Fe_2O_3 would not be capable of causing spontaneous combustion.
- Cobalt caused increased sensitivity when added in concentrations of 5, 10, 17.5, and 25 percent to the potassium chlorate-sulfur mixture.

- Stainless steel filings did not increase sensitivity when added in concentrations of 1, 5, 10, 17.5 and 25 percent to the potassium chlorate-sulfur mixture.

- Recrystallized potassium chlorate from aqueous solutions doped with copper chlorate, cupric nitrate, cupric sulfate, barium chlorate, and chromic chloride showed greatly increased sensitivity when mixed with stoichiometric amounts of sulfur.

- Aqueous potassium chlorate doped with copper chlorate at concentrations of 1, 5, 10, and 17.5 percent did not spontaneously combust at a relative humidity of 60 percent when mixed with stoichiometric amounts of sulfur.

- The likelihood of the formation of copper chlorate in a production plant constructed of copper or copper alloy is negligible.

- Copper salts such as cupric nitrate, cupric sulfate, and basic cupric carbonate increase the sensitivity of the potassium chlorate-sulfur mixture.

RECOMMENDATIONS

Based on the scope of this study it is recommended that copper and copper alloy tools and screens remain in pyrotechnics production plants because neither the oxidation products of copper (CuO or $Cu_2(OH)_2CO_3$) nor copper itself causes a significant increase in the sensitivity of a $KClO_3$-S mix, nor is it conceivable that any of the contaminants causing increased sensitivity ($Cu(NO_3)_2$, $CuSO_4$, $Cu(ClO_3)_2$) will be formed in the production process for reasons previously stated.

It is also recommended that a thorough review and, if necessary, revision of existing pyrotechnic procurement and manufacturing specifications to conducted to ensure the existence of regulations restricting the incidental incorporation of any amount of foreign compound in the end product which might increase the specified product sensitivity.

SUPPRESSIVE STRUCTURES FOR OPERATIONAL SHIELDING

Paul V. King
General Electric Company
Bay St. Louis, Mississippi

ABSTRACT: A requirement exists to provide operational shielding for a new production line for 4.2 WP chemical shells.

Because of limitations of space and money, an attempt has been made to develop a "Suppressive" concept of operational shielding.

Shielding design requirements are to (1) contain fragments of rounds and filler, (2) suppress fireball, (3) minimize afterburning. Results achieved to date indicate that the concepts applied are both economically feasible and safe.

ACKNOWLEDGMENT A number of persons have contributed ideas to the resolution of this problem. Special thanks are offered to Messrs S. Vogelein, G. DeRoy, P. Henderson, of Edgewood Arsenal, and Mr. W. Stone, General Electric Company.

INTRODUCTION: The development of new production processes for manufacture of WP rounds has resulted in a requirement for parallel development of new concepts of operational shielding. The work reported on herein is the result of attempts to develop a suitable shield to protect an operator at an adjacent station of a 4.2 WP mortar line in the event of an accidental initiation of the round in question.

At the present time various configurations have been developed and tested with the final prototype test scheduled for the week of September 8.

Experiments to date indicate that this concept is feasible and meets the objectives established.

PROBLEM: The requirements of the new production line are such that a very limited amount of space is available between adjacent operations. Although every attempt has been made to assure maximum safety for all personnel, there are several locations where it has been deemed necessary to provide a shield to protect personnel at adjacent locations.

The arrangement of the line is essentially one of stations occupying approximately five feet of width located on ten feet centers so that an operator might be as close as five feet from the 4.2 round.

This situation precludes the use of conventional reinforced concrete types of structures, and also the various types of vented or blowout panel designs.

It was decided that a different approach was needed for this application. The approach taken was based on the following assumptions and conditions.

HAZARDS ENCOUNTERED: Static firing of the 4.2 rounds indicated the following:

Fragment Hazard

- Severe - large fragments of excellent penetrating qualities resulting from shell case.
- Moderate fragment hazard from burster tube and from small pieces of WP.

Fire Hazard

- Severe - (Initial fireball) plus WP spray.

Blast Hazard

- Slight - no permanent injury to personnel located at five feet or more away.

In view of the limitations of space, and the need to prevent dispersal of WP spray, it was decided to attempt to design a structure which would permit excape of gases and venting of overpressure, while stopping fragments, and suppressing the fireball.

Another primary consideration was the need for a lightweight, easily dismantled facility to permit easy access to the line.

Briefly the problem appeared to break down into three basic design considerations.

a. Offer minimum resistance to blast overpressure (maximum venting).

b. Stop large fragments on inner wall surfaces.

c. Stop WP spray and suppress fire by utilizing the flash screen principle (as seen in the conventional flamable liquid dispensers).

d. Maximum utilization of off the shelf materials.

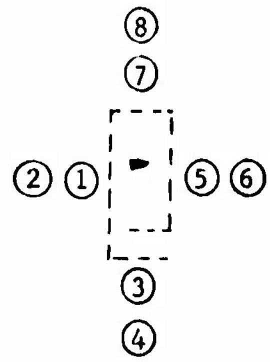
Initially it was felt that the side wall panels could be "free hung" to move with the blast and relieve pressure. The first few tests were made of layers of chain link fence, asbestos cloth and similar materials but were found to be relatively ineffective in suppressing flames.

Expanded metal panels of various geometries were next tried, and while effective in stopping major fragments, they did little to prevent dispersion of very small fragments.

Initial free air tests of the rounds established the basic blast, fragmentation and fireball parameters (Table I).

Table I. WP Operational Shield Tests
4.2 WP Mortar Round

Round Weight = 32 pounds
Burster Weight = 0.21 pounds
Booster Weight = 0.04 pounds
WP Filler Weight = 8.14 pounds



TRANSDUCER POSITIONS

CONFIGURATION	TRANSDUCER NO.	TRANSDUCER DISTANCE (R)	SCALED DISTANCE (R/W 1/3)	PEAK OVERPRESSURE (PSI-SIDE ON)	PERCENT REDUCTION (PSI)
Burster Only (Free Air)	7	8.0	12.72	6.6	--
	1	8.5	13.51	7.2	--
	5	8.5	13.51	6.8	--
	3	9.5	15.10	4.0	--
	8	11.0	17.49	4.5	--
	2	11.5	18.28	2.5	--
	6	11.5	18.28	3.0	--
	4	12.5	19.87	3.4	--
Complete Round (Free Air)	7	8.0	12.72	2.3	--
	1	8.5	13.51	1.9	--
	5	8.5	13.51	3.2	--
	3	9.5	15.10	2.0	--
	8	11.0	17.49	1.8	--
	2	11.5	18.28	1.2	--
	6	11.5	18.23	1.7	--
	4	12.5	19.87	1.55	--
Complete Round in Operational Shield Cubicle	7	8.0	12.72	0.65	72
	1	8.5	13.51	0.8	58
	5	8.5	13.51	0.8	75
	3	9.5	15.10	1.2	40
	8	11.0	17.49	0.75	58
	2	11.5	18.28	0.65	46
	6	11.5	18.28	0.5	71
	4	12.5	19.87	0.92	41 *
				Average	60%

*From complete round free air value

Briefly the blast overpressure measured at a scaled distance of 8.6 (burster charge weight 0.21 pounds + 0.04 pounds booster weight), (distance five feet) was felt to be of little concern (3 PSI).

The fireball diameter in free air was approximately ten feet and afterburning (assumed to be from WP spray) extended to approximately thirty feet (Figure 1).

The fragmentation characteristics were somewhat of a surprise. Although the fragmentation pattern was fairly uniform and predictable, the penetrating qualities of the major fragments exceeded our estimation (based on celotex penetration formula developed for wound ballistic criteria). Typical fragment penetrations in celotex are given in Table II.

Early shielding tests were performed in our UTF (universal test fixture) which is simply a three sided structure with test panels on the fourth side.

Since we were funnelling everything out the open side, the bias resulting served to provide a safety factor for early tests.

After we discarded the free hanging panel approach, we regrouped and went to the perforated wall approach, adopting as our initial design criteria the fundamentals of spaced laminar construction, lightweight materials,

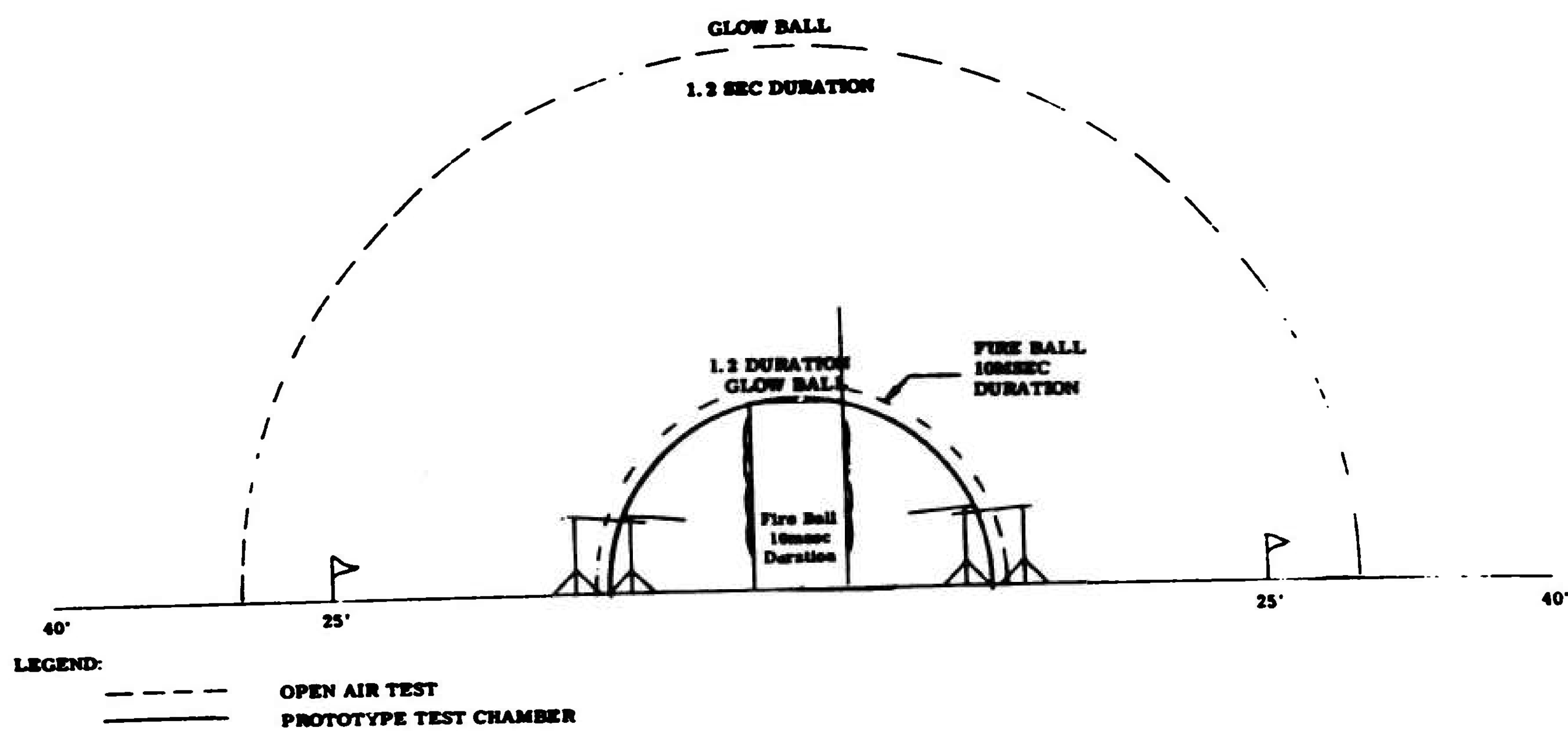


Figure 1. Glow Ball-Fireball Characteristics

Table II. Celotex Fragment Velocity

MASS (gms)	PENETRATION (in)	INCIDENT ANGLE	SIMPLIFIED EQN. VELOCITY (ft/sec)	GENERAL EQN. VELOCITY (ft/sec)
91.3	7.5	30^0	1869	-
49.4	13.0	20^0	3431	-
18.9	1.5	20^0	831	-
34.5	4.0	25^0	1537	-
40.2	6.0	0^0	1910	52,811
528.6	3.5	0^0	523	17,209

and staggered openings with approximately 30-40 percent of the surface open.

Various geometrical configurations were tested before we realized that at least for the parameters we had established - namely 30-40 percent of venting area, uniform hole geometry, etc. - there was always one point at which the openings lined up to permit a direct line of sight however small and however flat the angle.

Realizing then that we had to interrupt the symetry and that by working in the horizontal plane, our working "line of sight" would be limited by the floor and ceiling, we tried various configurations settling on a back to back louvre wall design (Figure 2).

The end wall of tests 11 and 12 consisted of the louvred concept with the remaining walls consisting of various other laminar configurations (Figure 3). The materials utilized included perforated steel sheets, expanded sheets, gratings, and ordinary copper window screen.

Results, as shown here, and as indicated by our passive sensors, have been highly gratifying.

Based on our last test (Table I), the environment seen by an operator five feet from the center of the round would look like this:

Blast Pressure approximately 0.6 PSI side on.

OPERATIONAL SHIELDING
LOUVERED WALL
DETAIL

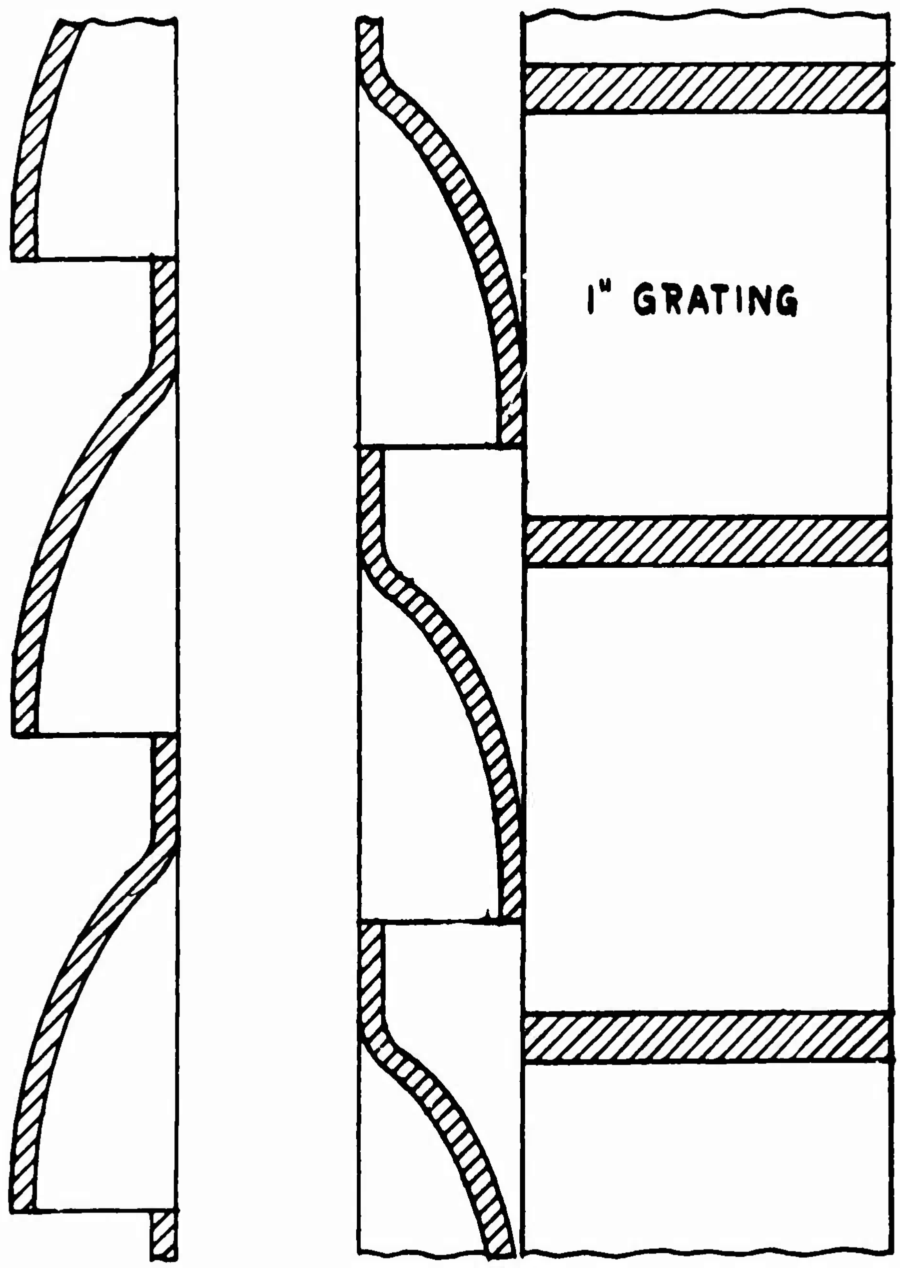


Figure 2

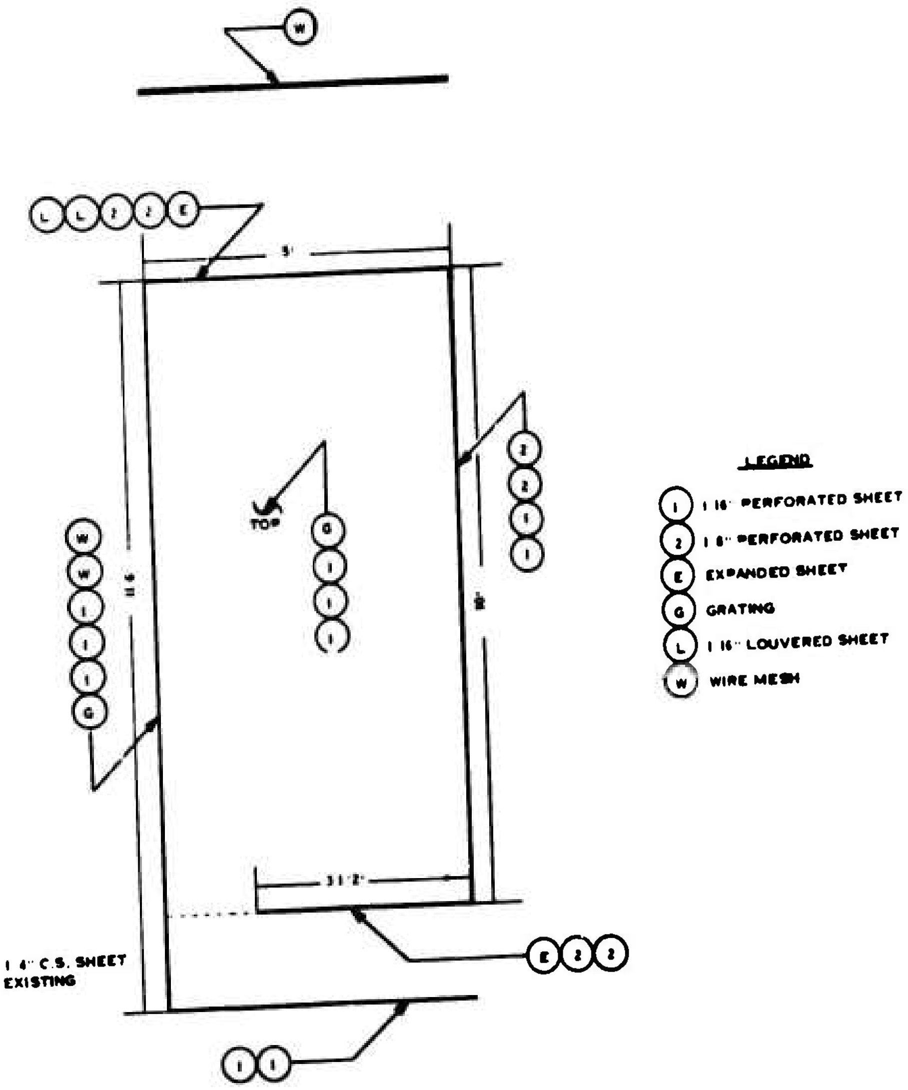


Figure 3. Test 11 and 12 Suppressive Structure

Temperature less than 200°F (radiant heat, no response on temperature tab sensors).

Fragments - none

WP Spray - none

Afterburning - insufficient to discolor or displace toiliet tissue, ham slices, bread.

Fireball Duration - 10 milliseconds

Afterburning - 1.2 seconds

NOTE: Additional validation tests conducted since date of presentation have indicated the following:

Fireball expansion, at final test panel, reduced by 56 percent. Based on the observation that the fireball was suppressed by the test panel five feet away, as compared to a free air diameter of approximately 11.5 feet.

Afterburning (Glow Ball) reduced by 80 percent from a free air value of 33 feet to a diameter of 6.5 feet at test panel (1.5 feet beyond panel). It should be noted that these distances were based on the observed effectiveness of the final test panel configuration in retaining the fireball, and in permitting only a slight penetration of the "glow ball", or afterburning. Although the panel might

be more effective at even closer distances, other design considerations would have to be evaluated, before any lesser distances were recommended.

IN SUMMARY: The "suppressive" or "breathing wall" construction developed for this operation is effective in modifying the environment seen by an adjacent operator to tolerable levels. The materials utilized for this construction are lightweight, relatively inexpensive, and easily removed or modified for service. Since the wall thickness required is less than three inches, the construction constraints have been complied with.

This concept may be applied to liquid and solid propellant exposures.

GROUNDING OF EXPLOSIVES LOADING AND STORAGE FACILITIES

Moderator:

Ray Coyle
Naval Ammunition Production Engineering Center
Crane, Indiana

VERIFYING BUILDING GROUNDING SYSTEMS

Prepared By
Ray Coyle
Naval Ammunition Production Engineering Center
Crane, Indiana

SECTION I

A. Scope. This document provides guidelines for verifying building grounding systems of Navy type ammunition production, renovation, handling, and storage buildings.

SECTION II

A. Applicable Publications

1. National Electrical Code -- Grounding Sections

2. National Fire Protection Association Code

3. Army Material Command, AMC Safety Manual, AMC Regulation AMCR 385-224, Section 7 and 8

4. OP 5 (Volume 1), Chapter 41, Ammunition Ashore Handling, Stowing and Shipping

5. NAVFAC - DM-4, Change 2, April 1969

6. National Bureau of Standards Technological Paper No. 108. Ground Connections for Electrical Systems

7. NAPEC Sketch #'s 69, 70, 72 and 73

8. WPEC Instruction, OI-03, Operation Instruction for Checking Building Grounding Systems

SECTION III

A. Lightning Protection. The purpose of lightning protection is to safeguard ammunition buildings and their contents by providing a conductive path of low resistance for the discharge of electrical current caused by electrical storms or static discharge of the clouds. Two types of protective systems are described in this document. They are the "primary" system, intended to prevent damage from direct strokes of lightning and the "secondary" system to prevent the metal parts of a building or its contents from accumulating charges of electricity which may cause sparks upon discharge. A production building should have both systems. Storage and some test buildings will have a secondary system only.

B. Primary System. The primary system consists of four or more masts each of which is twice the height of the building it protects. When four masts are used, they are placed at the corners of the building a distance of at least half the height of the mast from the building. The masts are metallic rod type of slip joint design topped with a non-corrosive metal cap. A 2/0 AWG bare copper cable is welded to the masts and to the ground terminal to form a closed loop about the building. The cable used to connect the masts and the ground terminal is called the "girdle" and is placed at least 18 inches below the grade. (See Sketch 69). The ground terminal, or earth terminal, as it is sometimes called, may be made of a large copper plate located below the water level of the subsoil and surrounded by charcoal. Ground rods may be used if moist soil cannot be reached. Any underground water pipe or other metal work near the primary girdle must be connected to the girdle by a similar cable using corrosion-resistant clamps.

C. Secondary System. Secondary protection is designed to prevent metal parts of buildings, building contents or other types of structures from accumulating electrical charges that can cause sparking. This system consists of a buried ground girdle to which all metal parts, including reinforcing steel of the building or other structure, are connected. An interior grounding bus may be utilized for the grounding of building contents. (See Sketch 70). The ground girdle for this system is of 2/0 AWG bare copper cable located at least 18 incnes below the grade and three feet from the building. The ends of the girdle are connected together to form a closed loop about the building. The girdle should be fixed by driven ground rods. Connections to the ground rods are made by a clamp type device to facilitate disconnection of the girdle from the ground rod for periodic testing. These are copper-clad steel rods driven into the ground to reach permanently moist soil. Connections to the secondary girdle or interior grounding bus are made with #6 AWG copper wire. Bonding connections from one grounded part to one to be grounded must not exceed 40 feet in length.

D. A primary system is used to protect production buildings or other upright structures containing explosives. Secondary grounding is used for earth covered magazines or non-production buildings.

E. Railroad tracks extending into buildings or alongside the building are independently grounded 10 feet or more outside the building. (See Sketch 73). A 2/0 AWG cable is welded to the tracks, buried a minimum of 18" under the grade level and connected to a ground in accordance with Sketch 73.

F. If the building under consideration is located in a wooded area, no trees may be left standing within a primary protection system. Beyond this area, but not closer than 50 feet or a distance equal to the height of the tree, trees are desirable.

G. If a single ground wire is to be used to ground more than one object, the connections to them must be made progressively lower in the direction of the ground rod. This is done because the very high voltage encountered when lightning hits will prevent the discharge from following the cable if the cable runs back toward the ceiling.

SECTION IV

A. Instrumentation. The most controversial subject in lightning grounding and testing is the method or the type instrument used. Some of the experts say only a three point system using 500 volts or more should be used. Others say a two point system should be used. We have found very little references to this subject but here are the facts in accordance with OP 5 and NAVFAC DM4.

1. OP 5 (Volume 1 - Page 41-3) states that a commercial instrument such as an ohmmeter or megger should be used. The instrument used must make use of a separate (or "test") ground.

2. Empressed Voltage: The National Bureau of Standards Report No. 108, page 163, shows a series of measurements of relatively low resistance grounds in which practically the same values of resistance were obtained with currents from about 60 amperes down to a few milli-amperes. From this we can see that the impressed voltage, (or current) has very little, if any, effect on the resistance readings.

3. The equipment used for grounding checks should be of the type capable of testing electrical wire insulation, earth ground, continuity, and circuit testing. The test equipment should have at least three ranges for measuring resistance.

SECTION V

A. Inspection and Test of Lightning Protection Systems. The resistance to ground of a primary system shall not exceed 10 ohms. A commercial instrument, such as an ohmmeter or a megger, should be used. The instrument used must make use of a separate (or test) ground. The manufacturer's instruction should be carefully followed in order to avoid damage to the instrument and insure valid results.

NOTE: The building to be tested for grounding status shall be completely and thoroughly cleaned/decontaminated of any explosive material prior to testing. A local fire permit should be issued prior to a grounding test.

B. The first and most important step when checking the condition of a grounding system is to establish a ground test point. This is done by driving a copper-covered steel rod having a diameter of from 3/8 inch to one inch sufficiently deep in the earth to reach permanently moist soil.

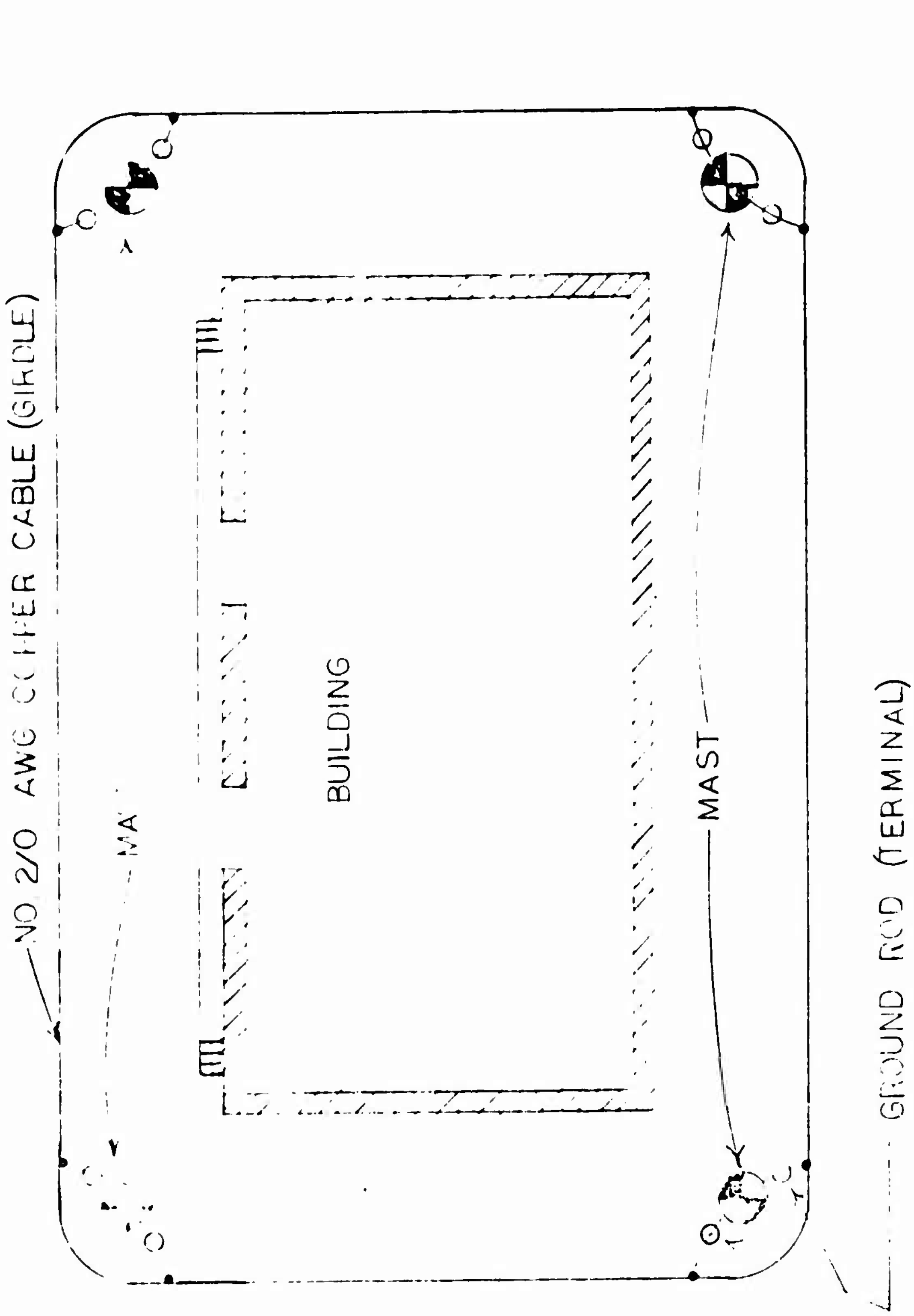
C. When testing a primary system, each mast shall have no more than 10 ohms resistance to ground, (test ground). When a secondary system and a primary system both are used, the secondary must also read 10 ohms or less to ground. However, when a secondary system is used alone, a reading of 25 ohms is acceptable when testing the resistance from the grounding girdle to the test ground.

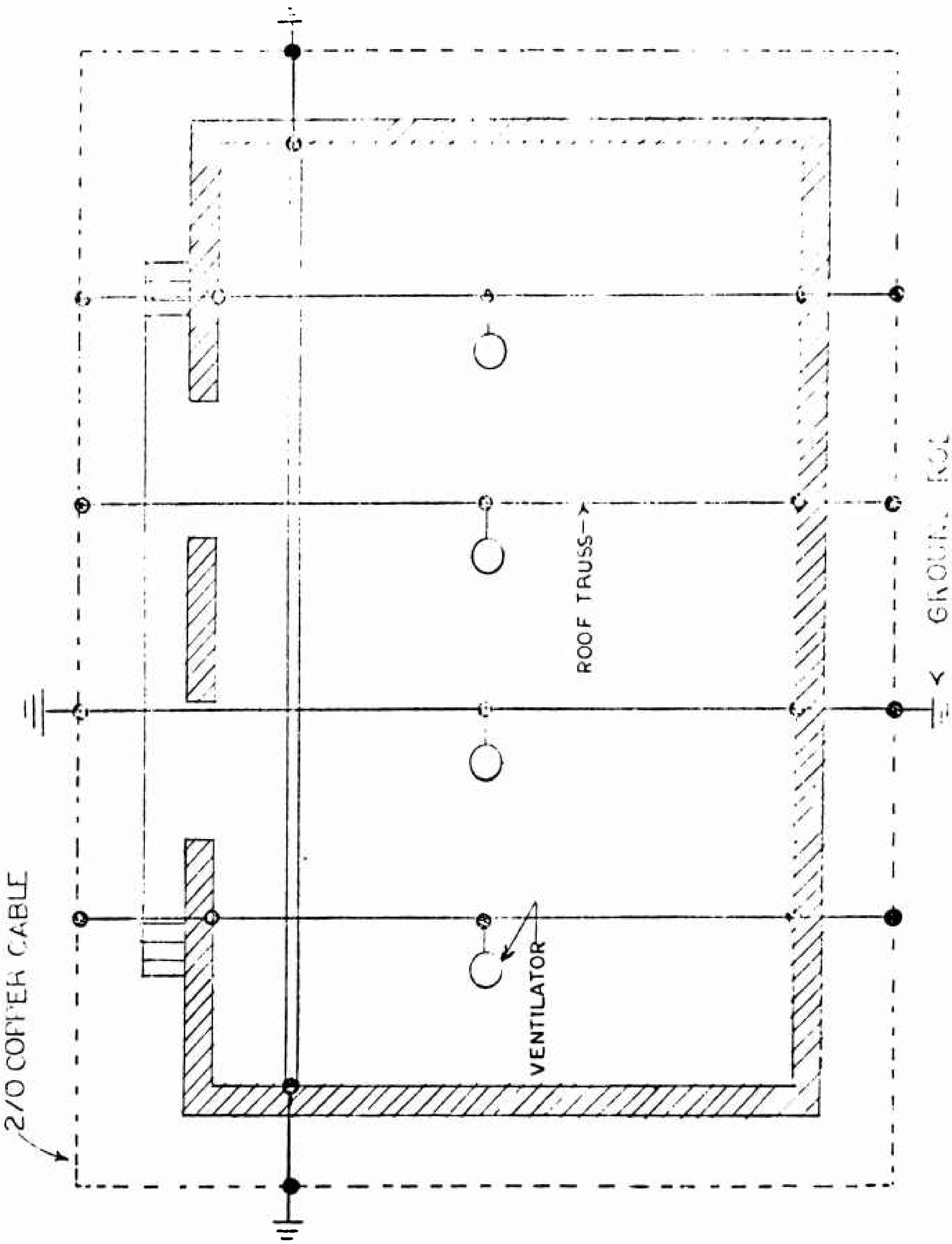
D. In paragraph C, section III, we have stated that no more than 40 feet of #6 cable shall be used to connect metallic items within the building to the grounding girdle. From the copper wire table, we find that 1,000 feet of #6 copper wire has a resistance of .4028 ohms. This would mean that the resistance to ground from a metal table within a building would have no more than the 10 ohms resistance permitted by the requirement of primary system plus the resistance of 40 feet of #6 wire or about 10.0016 ohms. Only very elaborate lab type test equipment would be able to measure resistance to four decimal places. It is reasonable to assume that the resistance from any metallic point, within a building protected by a primary grounding system, to the test ground (true ground), will be 10 ohms or less. In a building having only a secondary system, a reading of 25 ohms to true ground is acceptable.

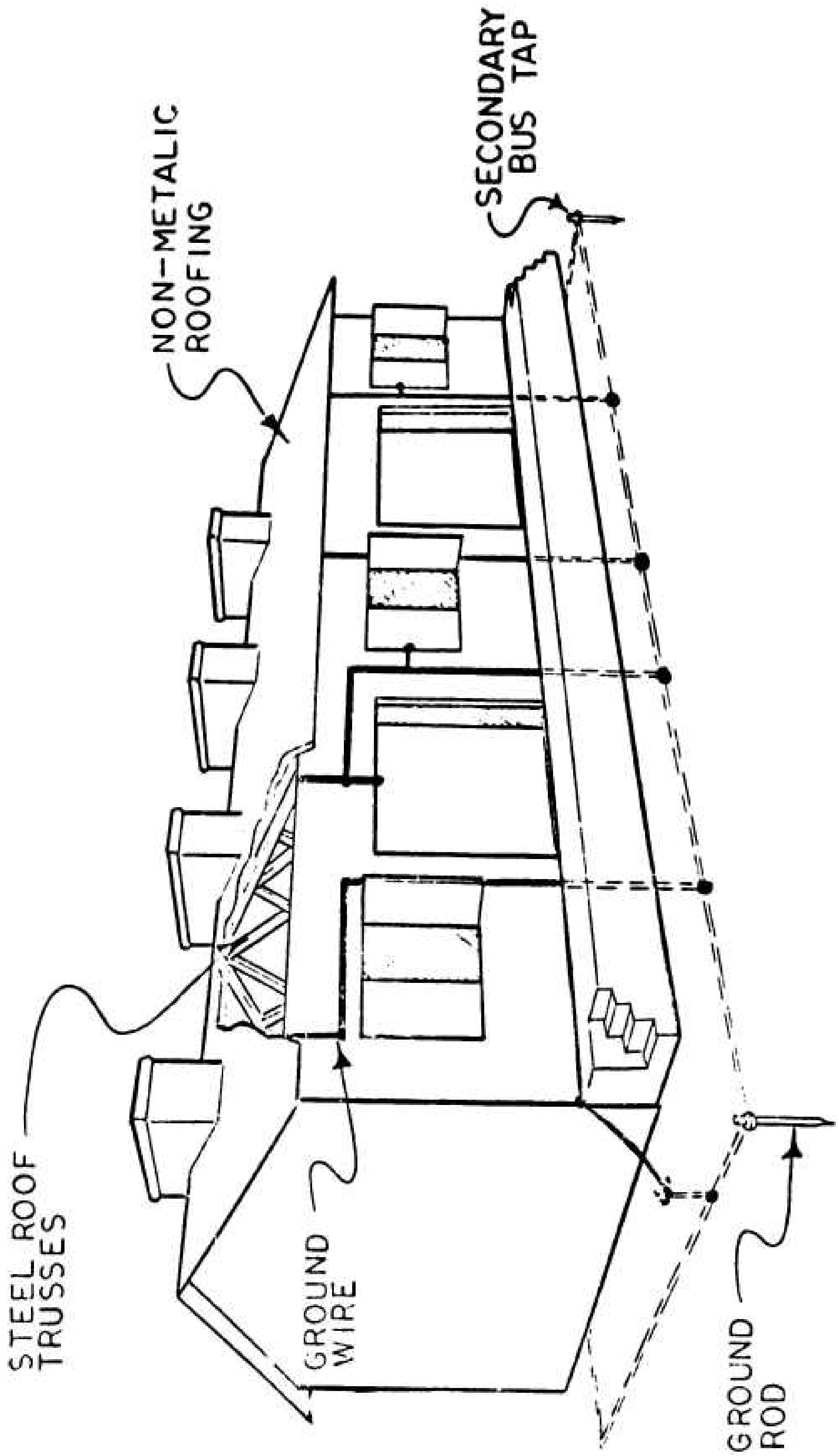
E. Semi-annual Inspection. The primary and secondary system shall be visually inspected semi-annually for evidence of corrosion and broken connections.

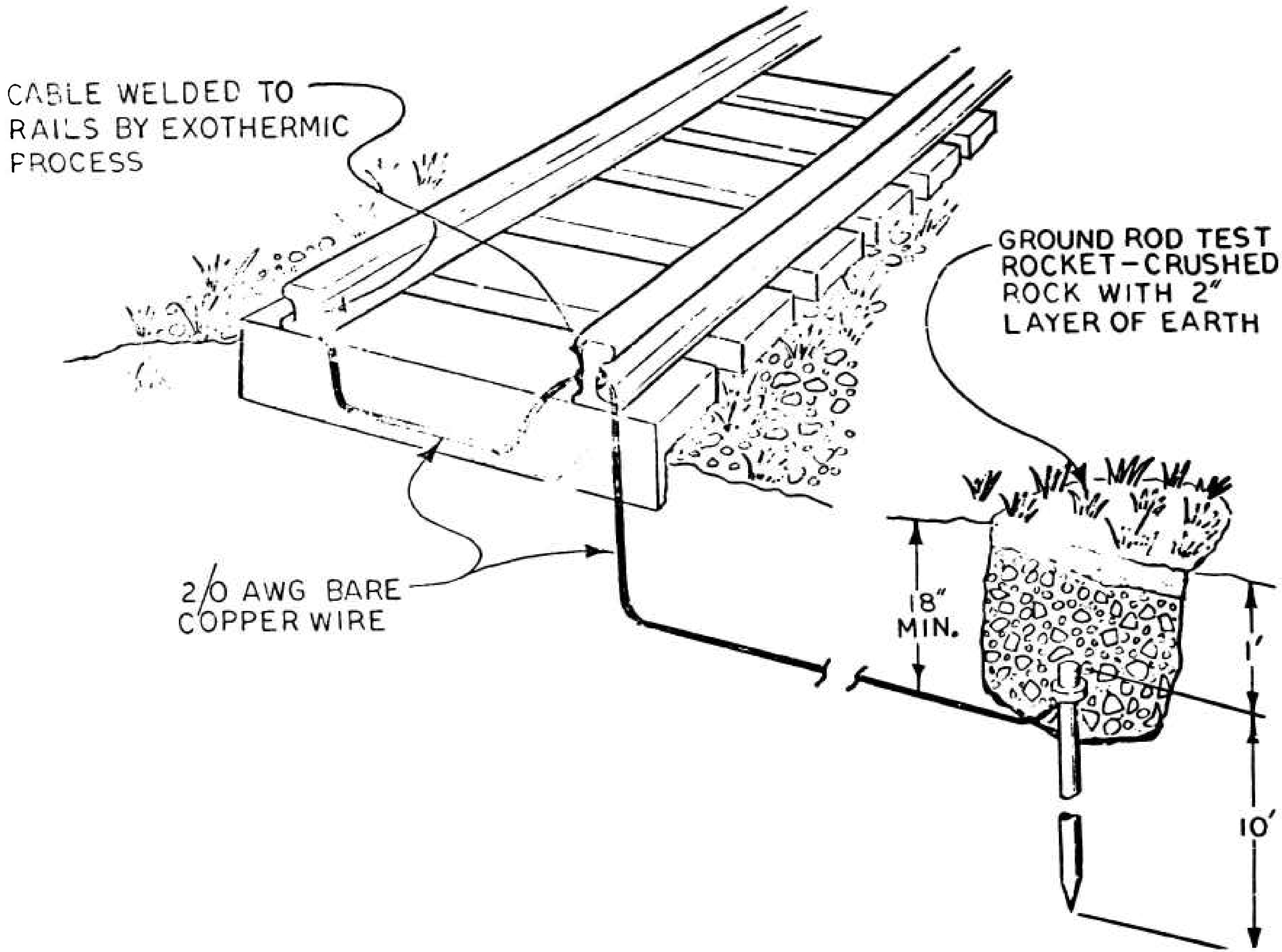
F. Annual Test. Once each year the system shall be tested electrically. The results of these tests, together with the description of the defects noted and the repairs made, shall be submitted to the person responsible for the efficient operation of the lightning protection systems and entered in the station records.

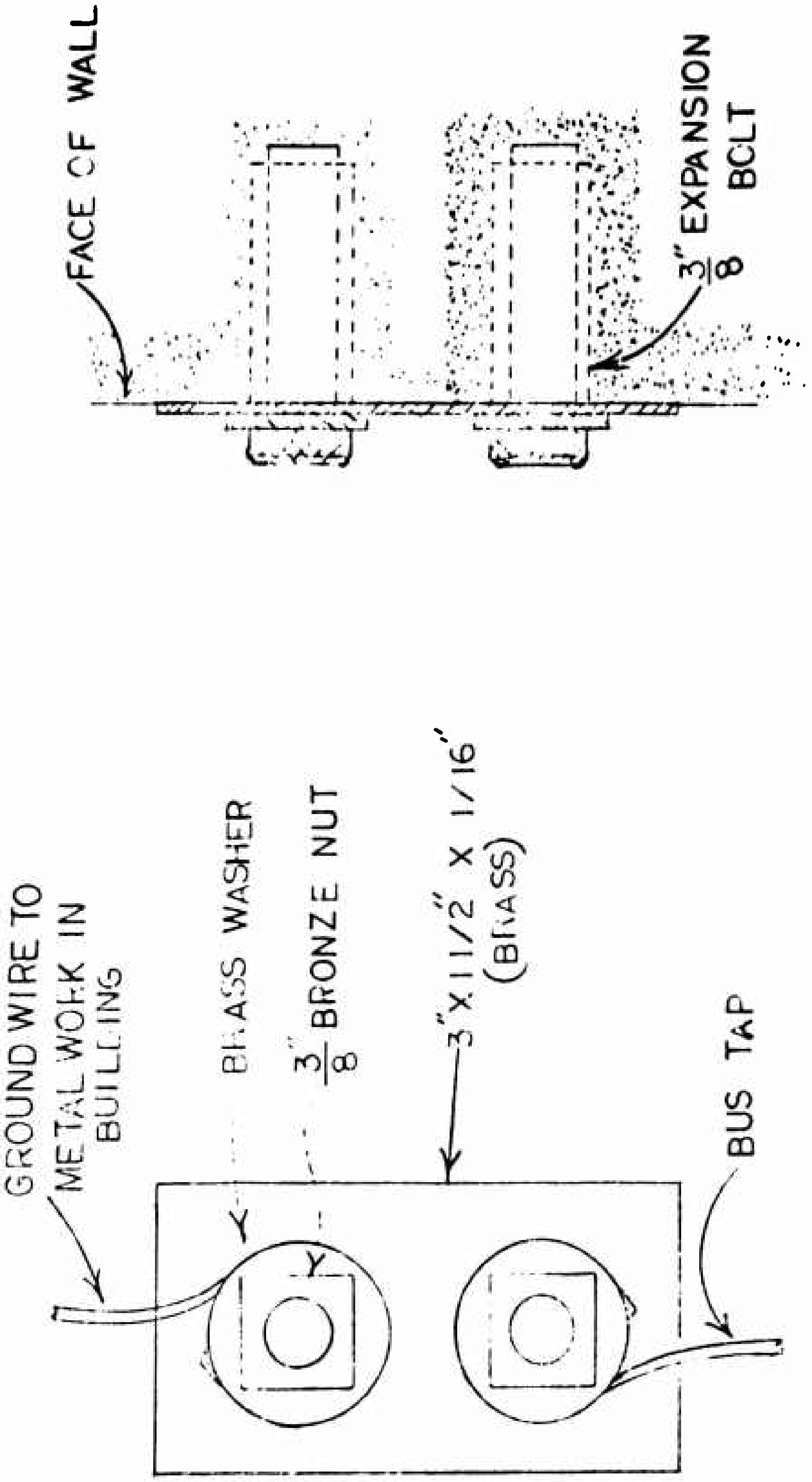
G. Unsatisfactory conditions are occasionally revealed as the result of inspection and/or tests of the grounding system that are not remediable by the station personnel. When such an unsatisfactory condition is observed, the report of inspection should be submitted to the safety section, NAVORDSYSCOM.


NO 2/0 AWG COPPER CABLE (GIRDLE)
BUILDING
MAST
GROUND ROD (TERMINAL)


2/0 COPPER CABLE
ROOF TRUSS
VENTILATOR


STEEL ROOF TRUSSES
GROUND WIRE
GROUND ROD
NON-METALIC ROOFING
SECONDARY BUS TAP


CABLE WELDED TO
RAILS BY EXOTHERMIC
PROCESS
GROUND ROD TEST
ROCKET-CRUSHED
ROCK WITH 2"
LAYER OF EARTH
2/0 AWG BARE
COPPER WIRE
18"
MIN.
1'
10'



FACE OF WALL
3/8" EXPANSION BOLT
GROUND WIRE TO METAL WORK IN BUILDING
BRASS WASHER
3/8" BRONZE NUT
3" X 1 1/2" X 1/16" (BRASS)
BUS TAP

COPPER-WIRE TABLE

Wire Size A.W.G. (B&S)	Diam. in Mils[1]	Circular Mil Area	Turns per Linear Inch[2]			Cont.-duty current[3] single wire in open air	Cont.-duty current[3] wires or cables in conduits or bundles	Feet per Pound, Bare	Ohms per 1000 ft. 25° C.	Current Carrying Capacity[4] at 700 C. M. per Amp.	Diam. in mm.	Nearest British S.W.G. No.
			Enamel	S.C.E.	D.C.C.							
1	289.3	83690	-	-	-	-	-	3.947	.1264	119.6	7.348	1
2	257.6	66370	-	-	-	-	-	4.977	.1593	94.8	6.544	3
3	229.4	52640	-	-	-	-	-	6.276	.2009	75.2	5.827	4
4	204.3	41740	-	-	-	-	-	7.914	.2533	59.6	5.189	5
5	181.9	33100	-	-	-	-	-	9.980	.3195	47.3	4.621	7
6	162.0	26250	-	-	-	-	-	12.58	.4028	37.5	4.115	8
7	144.3	20820	-	-	-	-	-	15.87	.5080	29.7	3.665	9
8	128.5	16510	7.6	-	7.1	73	46	20.01	.6405	23.6	3.264	10
9	114.4	13090	8.6	-	7.8	-	-	25.23	.8077	18.7	2.906	11
10	101.9	10380	9.6	9.1	8.9	55	33	31.82	1.018	14.8	2.588	12
11	90.7	8234	10.7	-	9.8	-	-	40.12	1.284	11.8	2.305	13
12	80.8	6530	12.0	11.3	10.9	41	23	50.59	1.619	9.33	2.053	14
13	72.0	5178	13.5	-	12.8	-	-	63.80	2.042	7.40	1.828	15
14	64.1	4107	15.0	14.0	13.8	32	17	80.44	2.575	5.87	1.628	16
15	57.1	3257	16.8	-	14.7	-	-	101.4	3.247	4.65	1.450	17
16	50.8	2583	18.9	17.3	16.4	22	13	127.9	4.094	3.69	1.291	18
17	45.3	2048	21.2	-	18.1	-	-	161.3	5.163	2.93	1.150	18
18	40.3	1624	23.6	21.2	19.8	16	10	203.4	6.510	2.32	1.024	19
19	35.9	1288	26.4	-	21.8	-	-	256.5	8.210	1.84	.912	20
20	32.0	1022	29.4	25.8	23.8	11	7.5	323.4	10.35	1.46	.812	21
21	28.5	810.1	33.1	-	26.0	-	-	407.8	13.05	1.16	.723	22
22	25.3	642	37.0	31.3	30.0	-	5	514.2	16.46	.918	.644	23
23	22.6	510	41.3	-	37.6	-	-	648.4	20.76	.728	.573	24
24	20.1	404	46.3	37.6	35.6	-	-	817.7	26.17	.577	.511	25
25	17.9	320	51.7	-	38.6	-	-	1031	33.00	.458	.455	26
26	15.9	254	58.0	46.1	41.8	-	-	1300	41.62	.363	.405	27
27	14.2	202	64.9	-	45.0	-	-	1639	52.48	.288	.361	29
28	12.6	160	72.7	54.6	48.5	-	-	2067	66.17	.228	.321	30
29	11.3	127	81.6	-	51.8	-	-	2607	83.44	.181	.286	31
30	10.0	101	90.5	64.1	55.5	-	-	3287	105.2	.144	.255	33
31	8.9	80	101	-	59.2	-	-	4145	132.7	.114	.227	34
32	8.0	63	113	74.1	62.6	-	-	5227	167.3	.090	.202	36
33	7.1	50	127	-	66.3	-	-	6591	211.0	.072	.180	37
34	6.3	40	143	82.6	70.0	-	-	8310	266.0	.057	.160	38
35	5.6	32	158	-	73.5	-	-	10480	335	.045	.143	38 - 39
36	5.0	25	175	103.1	77.0	-	-	13210	423	.036	.127	39 - 40
37	4.5	20	198	-	80.3	-	-	16660	533	.028	.113	41
38	4.0	16	224	116.3	83.6	-	-	21010	673	.022	.101	42
39	3.5	12	248	-	86.6	-	-	26500	848	.018	.090	43
40	3.1	10	282	131.6	89.7	-	-	33410	1070	.014	.080	44

[1]A mil is 0.001 inch. [2]Figures given are approximate only; insulation thickness varies with manufacturer. [3]Max. wire temp. of 212° F and max. ambient temp of 135° F. [4]700 circular mils per ampere is a satisfactory design figure for small transformers, but values from 500 to 1000 c.m. are commonly used.

OPERATION INSTRUCTION FOR CHECKING OF BUILDING PRIMARY AND SECONDARY GROUNDING SYSTEMS

Prepared By
Ray Coyle
Naval Ammunition Production Engineering Center
Crane, Indiana

WPEC-OI-3

OPERATION INSTRUCTION FOR CHECKING OF BUILDING PRIMARY AND SECONDAPY GROUNDING SYSTEMS

SECTION I

A. SCOPE: The purpose of this instruction is to provide a specific guideline for use in checking/verifying building grounding systems of Navy type Ammunition production, renovation, handling, and storage buildings. This instruction provides a step-by-step procedure with a typical building grounding system layout on WPEC Drawing No. 2222 and also describes the equipment recommended for use in this check.

SECTION II

A. APPLICABLE PUBLICATIONS

1. National Electric Code--Grounding Sections

2. National Fire Protection Association Code

3. Army Material Command, AMC Safety Manual, AMC Regualtion AMCR 385-224 Sections 7 and 8

4. Operation Instruction Manual for Biddle Catalog 822 Battery "Megger" Tester, James G. Biddle Co., Plymouth Meeting, Penn. 19462

5. OP 5 (Volume 1) Chapter 41, Ammunition Ashore Handling, Stowing and Shipping

B. Drawings

1. WPEC Drawing No. 2222

SECTION III

A. OPERATION/TEST PROCEDURE

1. Reference WPEC Drawing No. 2222 for the reference points used in making the required building grounding checks.

2. The building to be checked for grounding status shall be completely and thoroughly cleaned/decontaminated of any explosive material prior to checking. A local fire permit should be issued prior to a grounding check.

B. PROCEDURE

1. The equipment or equipments used for grounding checks shall be of the type capable of testing electrical wire insulation, earth ground, continuity, and circuit testing. The test equipment shall have at least three resistance ranges with three different testing voltages. The instrument shall have a low range capable of reading .1 to 1 OHM in .1 OHM increments with a test voltage of 4.5 volts D.C. or less. Suggested low range is 0-200 OHM's.

2. A medium resistance range of 0-5 megohms and infinity with a testing voltage of 7.5 volts D.C. or less is recommended.

3. A higher resistance range of 0-200 megohms and infinity with a testing voltage of 500 volts D.C. is recommended.

4. An example of one recommended test instrument is the Biddle Catalog 822 Battery "Megger" Tester (see Appendix).

5. For checking components of equipment and internal building grounding system, volt-ohm meters similar to the Simpson 260 are recommended.

6. Prior to making an electrical check of the building grounding system, the test instruments such as the Biddle Catalog 822 Battery "Megger" Test or Simpson 260 volt OHM meter shall be calibrated and the leads checked for continuity.

7. Resistance (maximum allowable in a 50 foot lead length of 2 OHM's). The person making this test shall be familiar with fundamental electrical principles and the Navy building grounding systems.

8. The first step required in this check shall be to establish a "Standard Ground Reference" point at the building site. This procedure is outlined in the instructions accompanying the Biddle Catalog 822 Battery "Megger" Tester. The accuracy of all subsequent readings are dependent upon the exact/precise location of this "Standard Ground Reference."

9. Points "D" and "E" on WPEC Drawing No. 2222 shall be used as "Standard Ground Reference." For the benefit of this document, point "D" shall be considered as absolute ground.

10. Points "1" through "6" are the "Air Terminals" and are connected electrically by cable according to Chapter 41 of OP 5 (Volume 1). These points are the "Primary System" for building lightning protection and shall be connected to the "Secondary System" (point 8) which is used for static grounding for the building and equipment in the building (for test purposes only and shall be removed following test).

11. With Point "D" as absolute ground, a resistance reading shall be made from point "D" to each of the "Air Terminals" (points "1", "2", "3", "4", "5", and "6"). A reading of 10 OHM's or less shall be required on each leg. Readings greater than 10 OHM's shall be cause for disapproval of the "Primary" grounding system.

12. The resistance readings from points "D" to "E" shall also be 10 OHM's or less to be acceptable or satisfactory.

13. This established point "E" as a reference point that is 10 OHM's or less above true or absolute ground. With this established reference point "E" known, the next step shall be to start checking the grounding system within the building.

14. Attach one lead of the test instrument to point "D" and check the resistance from point "D" to point "C." The resistance reading from point "D" to point "C" shall be 10 OHM's or less to be acceptable.

15. All of the above resistance readings shall be made to assure point "C" within the building is within 10 OHM's or less of true or absolute ground. The grounding "Standard" as described in paragraph 8 to the inside building grounding system as a test reference point. Use point "C" as a tie point for one lead of the test instrument and check all points within area 11 for ground.

Note: The lead from the test instrument to point "C" shall be a large insulated conductor having enough length to allow all points within the area to be reached and have a resistance of less than one OHM throughout

the lead length when checked separately. All equipment (machines, tools, equipment frames, equipment components) and metal items connected within area 11 shall have a resistance reading of three OHM's or less when checked to point "C" to be acceptable. (A more realistic reading would be 1.5 OHM's.)

16. Use point "C" again as a ground reference point and establish point "B" in another part of the building as a new ground reference point. The resistance between point "C" and point "B" shall be one OHM or less to be acceptable. This depends on the internal resistance of the lead lengths of the test instrument which shall be considered.

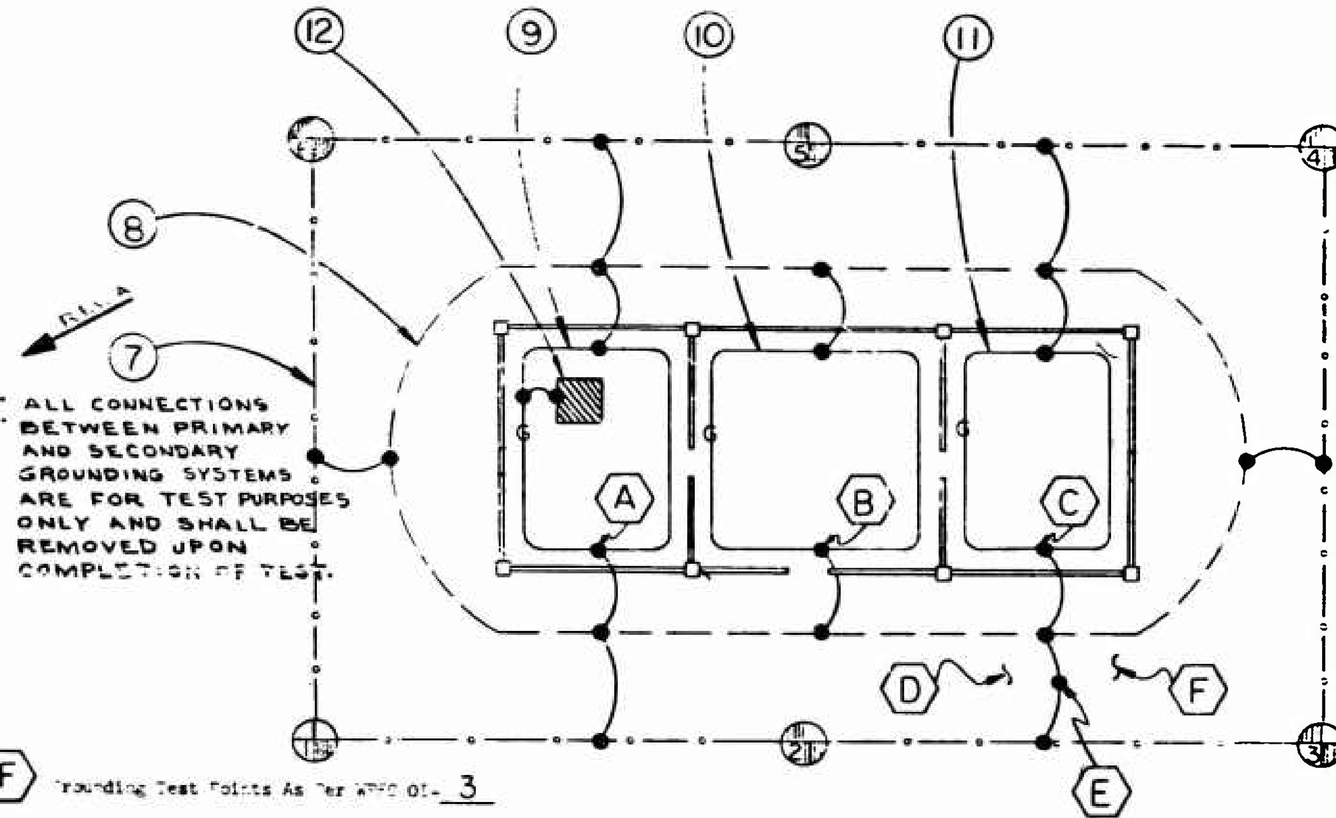
17. With the establishment of point "B" as a ground reference point, all equipment within area 10 shall be measured for resistance to ground and continuity as was done in area 11 using point "C" as a reference.

18. Area 9 shall be checked in an identical manner as would all building areas within any building.

19 All resistance readings taken shall be recorded on a form data sheet and dated. All future tests then can be compared with previous test with any grounding deterioration being evident.

NOTICE: THE CONTENTS AND DESIGN DETAIL OF THIS DRAWING WERE DEVELOPED BY THE WEAPONS PRODUCTION ENGINEERING CENTER AND ARE UNITED STATES GOVERNMENT PROPERTY

REVISIONS			
SYM.	DESCRIPTION	DATE	APPROVAL



NOTE: ALL CONNECTIONS BETWEEN PRIMARY AND SECONDARY GROUNDING SYSTEMS ARE FOR TEST PURPOSES ONLY AND SHALL BE REMOVED UPON COMPLETION OF TEST.

(12) Equipment Grounded to Room Grounding Girdle — G —

(11) Building/Room Grounding System Girdle

(10) Building/Room Grounding System Girdle

(9) Building/Room Grounding System Girdle

(8) Secondary Grounding System Girdle

(7) Primary Grounding System Girdle

6 Air Terminal (Lightning Mast)

5 Air Terminal (Lightning Mast)

4 Air Terminal (Lightning Mast)

3 Air Terminal (Lightning Mast)

2 Air Terminal (Lightning Mast)

1 Air Terminal (Lightning Mast)

Typical Navy Building with Typical Grounding System

(F) Grounding Test Points As Per WPEC OI-3

(E) Grounding Test Points As Per WPEC OI-3

(D) Grounding Test Points As Per WPEC OI-3

(C) Grounding Test Points As Per WPEC OI-3

(B) Grounding Test Points As Per WPEC OI-3

(A) Grounding Test Points As Per WPEC OI-3

DO NOT SCALE THIS DRAWING
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES.
TOLERANCES:
DECIMALS ± .005
FRACTIONS ± 1/64
ANGLES ± 0°-30'
REMOVE BURRS & SHARP EDGES
SCALE:

APPROVED: 2/17 1969
James F. Weller
DIRECTOR

		DATE
EXAMINED		
EXAMINED		
DESIGNED		
CHECKED		
DRAWN	J. K.	

Ground Test Procedure For Checking Building and Equipment

MATERIAL: REF. WPEC-OI-3

ASSEMBLY DRAWING No.	No. REQ'D.

DEPARTMENT OF THE NAVY
BUREAU OF NAVAL WEAPONS
WEAPONS PRODUCTION
ENGINEERING CENTER
CRANE, INDIANA

WPEC DRAWING NO.
2222
SHT 1 OF 1

K-E ALBANENE TRACING PAPER

AUTOMATION OF DEFUZING OPERATIONS

Moderator:

C. R. Goff
Day & Zimmermann, Inc.
Lone Star Division
Texarkana, Texas

THE AMORTIZATION OF AUTOMATING HAND OPERATIONS

C. R. Goff
Day & Zimmermann, Inc., Texarkana, Texas

There is an old saying in safety that you can't put a dollar value on safety. This is, of course, a very true statement, but in many cases it is used as an alibi to keep from having to actually analyze production problems. All of us are prone to resist change, especially if it involves a considerable amount of work or requires a complete change from accepted methods of doing work. There is also another time honored quotation that deserves attention, and that is that nothing can remain status quo but must either advance or retard. Day & Zimmermann, Inc., contract operators of the Lone Star Army Ammunition Plant, being basically an engineering firm, believes that advancement is a day by day and a vital and energetic part of any successful business.

It is true that at times in order to improve the safety factors of certain operations, that costs may increase, but it is equally true that in the majority of cases that safety can be greatly improved at the same time that production and quality are improved with a resulting substantial decrease in over-all costs.

A vigorous safety program can, when properly guided, inject into the lower echelon of management which is the group that is to develop new methods, the positive belief that proper consideration of safety problems reduces costs and rarely, if ever, increases ultimate cost. It is recognized that this statement could generate considerable disagreement, but for the moment let's analyze how this may work. Motivation is a great thing, but in order for it to be more than just a word, it requires action and safety can be the spark plug to inject into the personnel responsible for new ideas. Since injuries to personnel must always remain the prime concern of safety, there are two basic ways of eliminating injuries. One is to adequately shield the individual by either material or distance or remove the individual and have that portion of the work done mechanically. Since the shielding of an operator can only increase the cost, the obvious solution is to replace the operator with a mechanical device.

Amortization must be considered in the replacement of the individual in order to insure that engineering efforts expended provide a sufficient dollar return. In other words, if the safety risk was minimal and the amortization cost of the mechanical device was to extend for 5 years, the engineering effort required would not be good business. Fortunately,

there are many areas where the cost of amortization can be realized in a relatively short time span, thereby not only improving the safety posture and in many cases improving the quality and production capabilities but also affording long range acrual of dollar savings.

I have several examples of changes to equipment that not only were amortized in a relatively short time, but are now and will continue to return a substantial dividend in reduced costs.

The 81MM Mortar final assembly requires inserting and torquing the M82 Primer in the tail assembly. This torquing is done through positioning of an adapter with two pins that match holes in the base of the primer and should one of these pins accidentally contact the center of the primer, it could and has caused the primer to fire. In order to eliminate the possibility of human error and possible subsequent injury, a dial type machine was designed that automatically torqued the primer in the tail fin assembly. Since the possibility of an incident would be a flash fire and not an explosion, the machine is shielded with 1/2" plexi-glass and each mortar is shielded from the adjacent mortar to prevent propagation. Figures 1 and 1-A.

As a result of unfavorable storage problems overseas, it became necessary to jungle wrap the completed mortar to insure that moisture did not cause a hang-up in the mortar tube. An automatic chain conveying system with a dual hot dip type tank arrangement was added to the system to reduce personnel exposure and at the same time increase production capabilities. This equipment was amortized in June of 1968, and at that time showed a cost savings of $629,000. It is still in use and the subsequent cost savings and increased protection of personnel values are still being realized. Figures 1-B and 1-C.

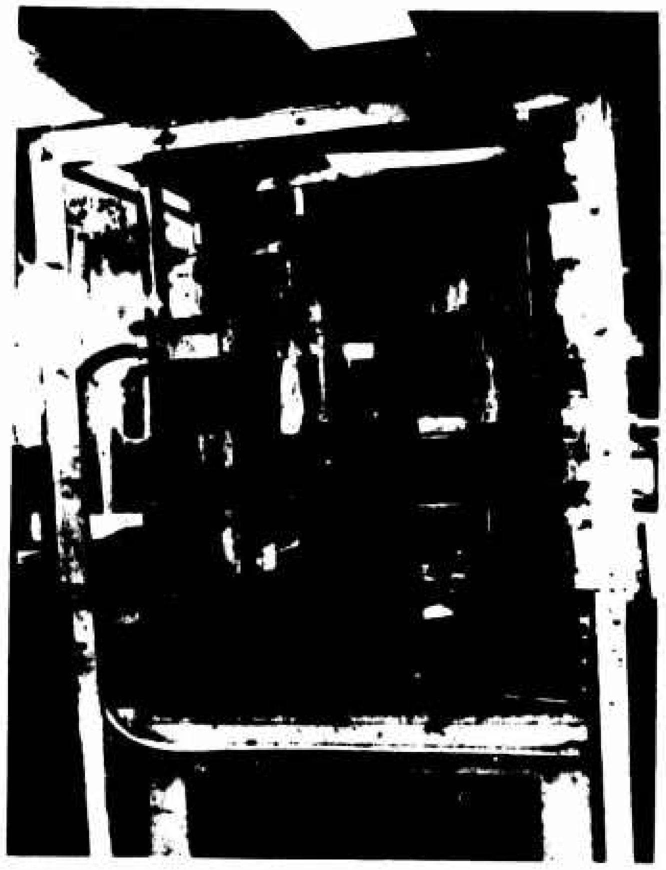


Figure 1

Figure 1-A

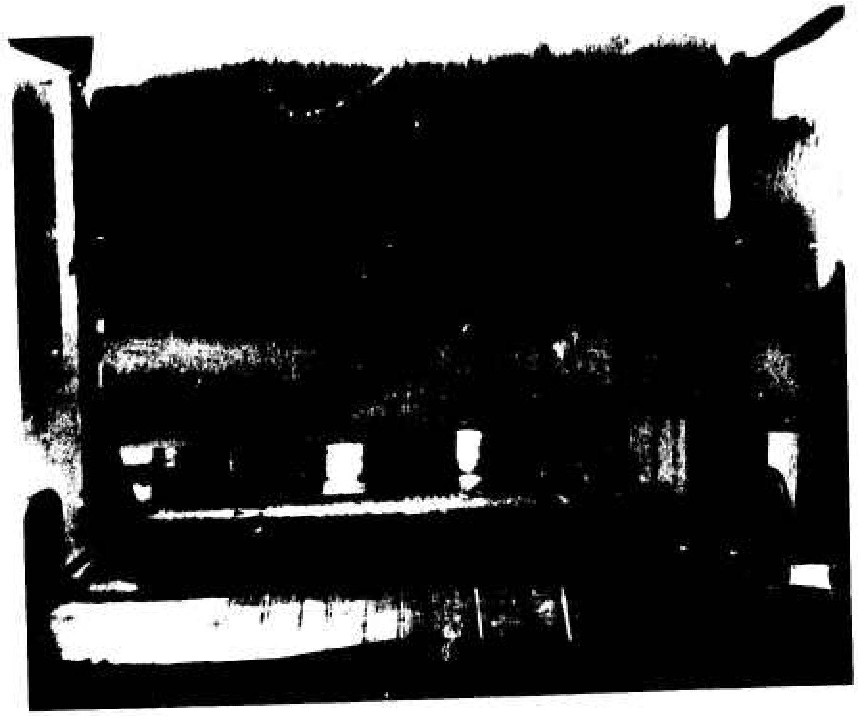


Figure 1-B

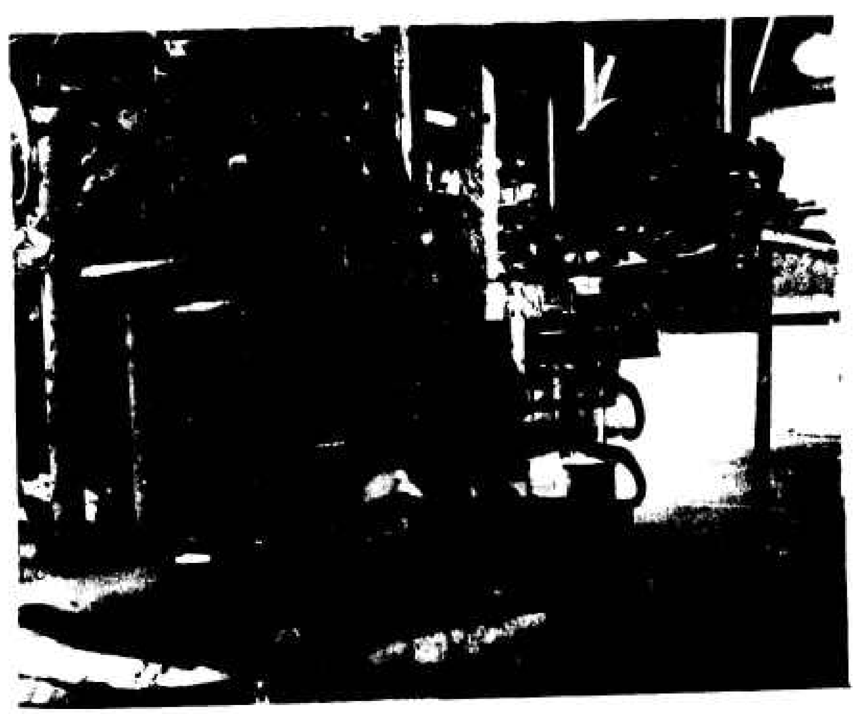


Figure 1-C

The loading of hand grenades, because of the minimum safety that has to be built into the grenade fuze, has always been considered a hazardous operation especially while the grenade fuze is being assembled and torqued to the grenade body.

In order to reduce to an absolute minimum, the hazards related with fuze insertion and torquing to the grenade body, a rotating dial was designed to match the station spacing of the cup conveyor utilized in the hand grenade assembly. This rotating dial is located behind a 1" thick steel barricade of sufficient size to insure that should something occur to the fuze during the torquing operation, the fuzed grenade would remain in the steel barricade for a minimum of 15 seconds or over twice the length of time required for the delay portion of the fuze to function. There is a steel access door that is automatically locked with an air cylinder any time the machine is in operation, and this door cannot be opened for a minimum of 12 seconds after the torquing machine has stopped. This also is to prevent an injury should an incident occur due to the delay portion functioning of the grenade fuze.

The torquing machine itself consists of individual torquing stations that are spring loaded and are cammed down, synchronized with the grenade conveyor chain, and so timed that the grenade fuze torquing operation is complete before the cam releases the grenade fuze. Built into these individual torquing stations is an automatic slip clutch arrangement that prevents over-torquing of the grenade fuze. This equipment was amortized in 200 shifts and has been in operation for nearly three years during which time not only are we realizing continued cost savings, but have entirely eliminated the possibility of employee injuries during grenade fuze torquing operations. Figure 2

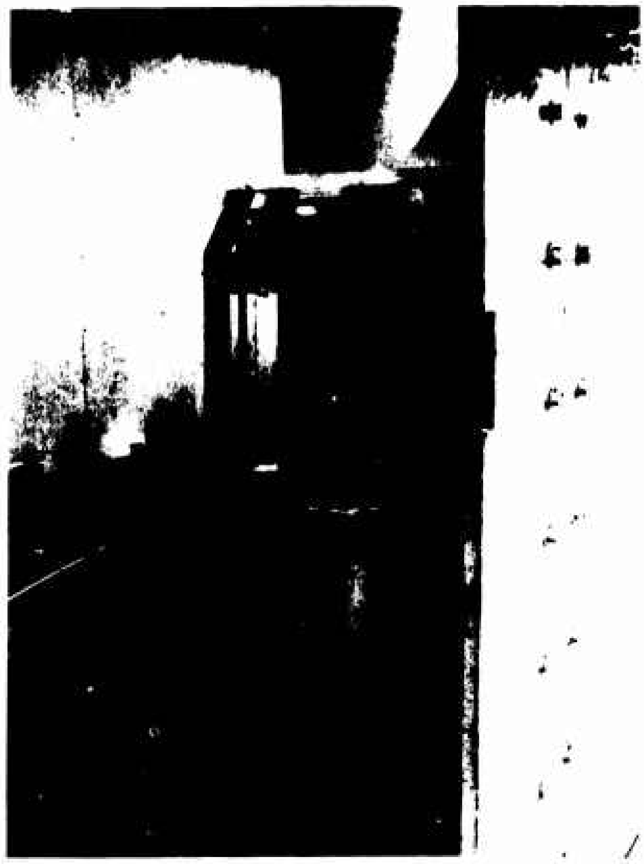


Figure 2

The M-19 and M-47 Burster operation was originally set up on a hand line using a series of operational steel barricades for the consolidation of the pellets. The exposure of the personnel working in that bay to a possible explosion even though shielded by a steel barricade was of considerable concern.

On the original hand line, we started out with a production level of 1,800 per shift utilizing 19 operators and this production level eventually reached 6,000 per shift, and even though our cost per burster was at an acceptable level, the personnel exposure was not.

A machine was designed that would automatically feed the necessary number of pellets into the steel burster tube and consolidate these pellets, two at a time until the required number of pellets filled the burster tube. The machine was located behind the concrete dividing wall with automatic feed for the empty burster tubes and automatic ejection and returned through the concrete dividing wall of the loaded burster tubes. This one piece of equipment replaced all 7 operators who had previously been operating the individual steel barricaded reconsolidating presses, thereby reducing the personnel exposure to zero. The production rate of 6,000 per shift was quickly reached and can be increased to 7,200 per shift if necessary. The machine amortized itself in 63 shifts at a cost savings of $223,000.

This was over a year and a half ago and obviously cost savings are still being realized. This one piece of equipment graphically demonstrates the value of examining an operation with the thought in mind of not only reducing but eliminating completely the primary safety hazard, and instead of thinking how much money will this cost, the thought was how much money can we save by the elimination of unnecessary operators. Figure 3.

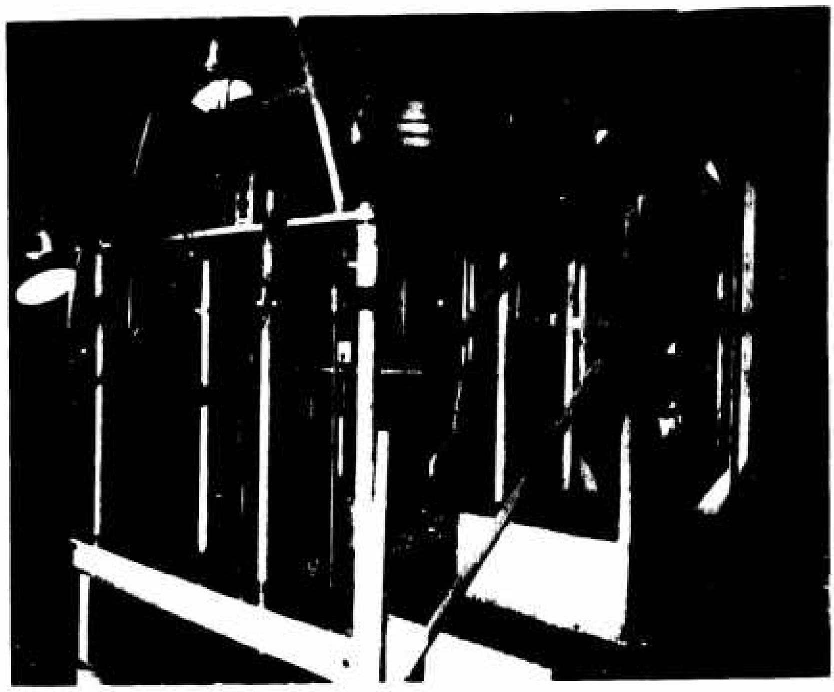


Figure 3

Loading of the XM9 Relay was being done on a hand line system. Twenty-eight operators on a three-shift, two-bay basis were being used to meet production requirements.

Semi-automating by using a barricaded Chamlee Loader to dispense the initiating explosives, and a Ferguson Intermitter (a dial indexing machine) to cut the closing disc, place the closing disc, crimp 45° and 90° and selection abilities provided an immediate effect of improved quality, more quantity, and a reduction of 5 people per shift. This all amounted to a total cost savings of $87,000. The equipment and installation costs were amortized in 20 shifts in production savings.

Full automation using a Ferguson Transomator tooled for the XM9 Relay element provided for a considerable reduction in personnel exposure. From a three-shift, two-bay semi-automatic loading method, using a total of 123 operators, to a two-shift, one bay fully automatic operation using 18 operators. The product quality went up, personnel exposure went down and the total cost savings amounted to just over $900,000. The amortization for retooling of the Transomator occurred in 7.5 shifts in labor costs. The equipment is still in production and is maintaining its record of cost savings.

The real benefit comes in personnel exposure. While not minimizing production cost savings, safety engineering must be concerned first with reducing the number of people exposed to a potential hazard. Figures 4 and 4-A.

Figure 4

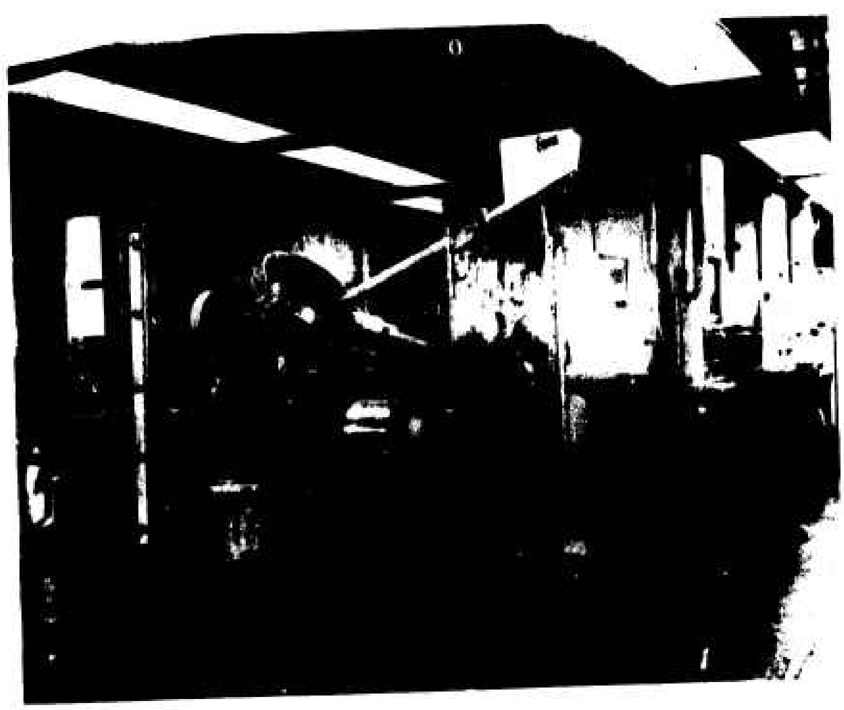


Figure 4-A

Production started with one single action press to manufacture M904 Booster Pellets. Production schedules increased, so eventually five single action presses were in operation. This required 14 operators. Installing one Colton 918 Rotary Press eliminated four presses, eleven operators, and four potentially dangerous explosives operations. The one rotary press produced more pellets per shift than all five of the single action ones combined. The rotary press, its associated automatic powder feeder, and the conveyorized pellet exiting system amortized in 24 shifts, eighteen months ago and is still in production today. Cost savings amounted to $136,000, but look at the reduction in personnel exposure, from fourteen to three.

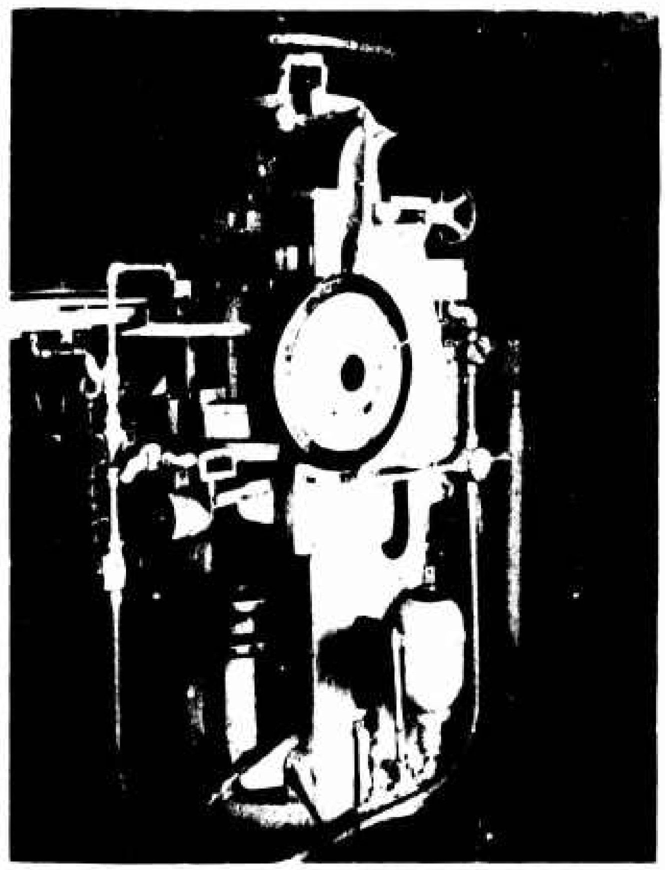


Figure 5

The loading of the M-9 Delay Element was being done on a hand line setup using 13 people per shift on a two shift basis. Converting to a modified Jones Loading Machine with a Cargile Scooper to load Delay Mix, an automatic percussion element loading system, plus the consolidation, crimping, and an ejection system that was selective for good or reject parts, provided an immediate safety benefit by reducing the personnel required to four operators per shift.

Further benefits proved to be better quality, and in a short time, more production. The total savings in money value turned out to be $123,000 in round numbers. The equipment costs were amortized in 80 shifts approximately 1-1/2 years ago, and it is still in production at this time. Further modernization of the M-9 Delay assembly system is being done now and personnel exposure and costs will be further reduced.

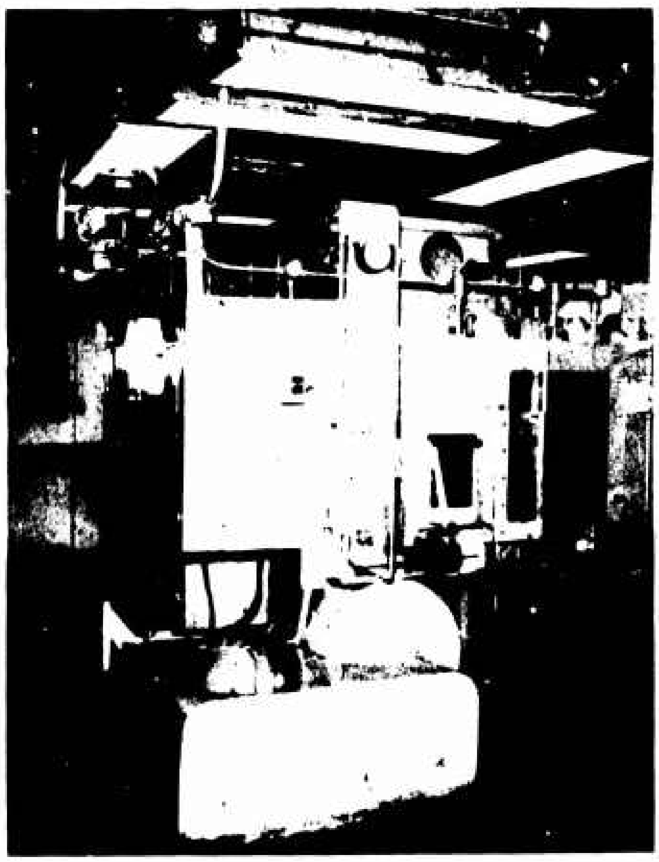


Figure 6

One of the ammunition component items that has continually been of great concern is the loading of sensitive initiating devices. A common machine used for this loading is the Jones Loader and as delivered from the manufacturer does not have any automatic feeding or ejection devices. Several years ago Day & Zimmermann, Inc. designed automatic metering devices for sensitive initiating explosives that materially reduced the injury potential associated with this machine. There still remained the operation of manual removal of detonators from the ejection tray and placing such detonators into a packing carton of 50 detonators. Fig. 7

Several plants have experienced serious injuries at this point of operation and Day & Zimmermann has designed and fabricated equipment that attaches to a standard Jones Loader that will automatically remove the loaded detonator from the dial of the Jones loader and place it into a magazine containing 50 holes. This magazine is an exact reproduction of the required packing tray and it is a simple matter for the operator to place a packing tray over this magazine and invert the magazine permitting the detonators to slide into their proper position.

Although this only resulted in the reduction of one employee which may not seem of great importance, it entirely removed personnel exposure to a hazardous item at a critical point in its production. This attachment was amortized in 120 shifts over a year ago and we now have four in operation.

Figure 7

Not all cost savings or reduction of incident potential come just from automation. For example, an engineering design change suggested by a mechanical engineer in the primer holder of the M-2 Delay primer body, by increasing the diameter of the primer hole .005 + a 45° chamfer in the bottom of the primer hole, improved production capabilities on this item so that a syntron feed system (barricaded) for the M-54 Primers and another syntron feeder for the primer holder could be built around an automatic seating punch -- then the good things happened. The hand operation of six operators on three shifts went to one operator per shift; quality went from 20% rejects on static firings to just below 5% on static firing. This had been a rather hazardous hand operation because of the two-handed finger tip nature of the job. The cost savings of $963,000 on this item was considerable. However, removing the incident potential was even more important. Amortization of this equipment occurred in twelve shifts nearly two years ago. The equipment is still in production today.

Figure 8

The IBM floating fixture fuze machine equipment has been discussed at other sessions, and its benefits to production and safety are fairly well known, but during the operation of this nearly totally automatic equipment, improvements do show up in pre-assembly of parts and further automation of some semi-automatic stations. For example, production was required to assemble some several hundred thousand fuze without a copper sealing disc in the closing screw. The operation started out as a mallet and hand tool operation, using three operators per shift to keep the automatic assembly equipment supplied. A single modified Verduin Press was installed to do this operation on a one-operator per shift basis. The resulting cost savings amounted to $89,000, and six people were removed from a hand operation hazard. Amortization for the press modification and installation occurred after 22 shifts. Figure 9.

The rear body assembly for the fuze was being hand placed onto the floating fixture pallet. This required two operators on a three-shift basis. When an automatic body placing was installed, the two operators were replaced and production increased from 11,000 plus per shift to 14,000 plus per shift. The total cost of the automatic body station was $8,000 and the resultant savings amounted to $80,000. Again operator exposure is a direct benefit to safety experience. Figure 9-A.

The setting sleeve assemblies for this fuze were being assembled on a hand line operation. The very small springs had to be packed end to end on a wire to prevent spring entanglement. This automation included an electromagnetic seperator which allowed the springs to be bulk packed. Using an existing machine from a previous fuze assembly operation, retooled to fit the setting sleeve requirements, four operators of a three shift basis were no longer required. The savings in bulk packaging of the springs alone paid the amortization costs of the equipment and installation. The savings in labor amounted to $220,000. Again, operator exposure was reduced to a bare minimum of one operator. Fig. 9-B.

Because of an embossing requirement for lot numbers and nomenclature in the fuze body, a sealing lacquer operation had to be done. At first this was done by hand. Not only was this messy, it was crowded, and there was some doubtful quality, too. So automatic lacquering equipment was designed and installed. Promptly, two operators were released,

quality improved, housekeeping improved and a potential bottleneck was eliminated. Total savings here amounted to $32,000; amortization occurred after 30 shifts on this piece of equipment. Fig. 9-C.

M-125 Boosters were assembled and torqued, by hand, to the fuze body. An automatic station of gear driven "Vee" belts was assembled and put into the floating fixture line. This station did all of the torquing requirements and two operators were relieved. Again, quantity at this station went up and a bottleneck was removed. Amortization of the station occurred in fifty shifts and a savings of $82,000 resulted. This may be a tiresome report, but operator exposure again was reduced. Figures 9-D and 9-E.

In these actions on these units of assembly systems, a savings of $500,000 was realized. All of the automated stations have been amortized from six to ten months and are in production today. Best of all, 16 operators per shift were removed from our potential incident projection.

Figure 9

Figure 9-A

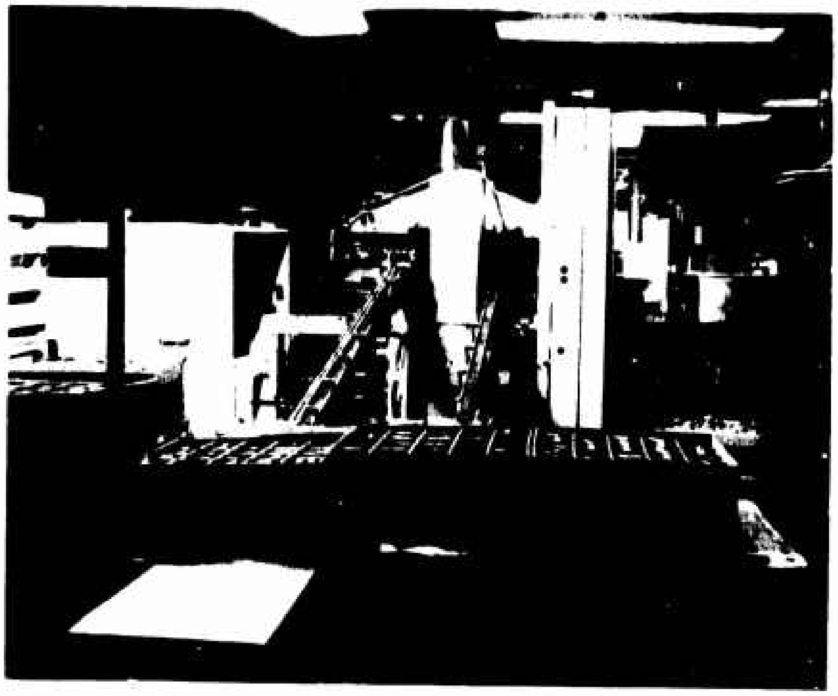


Figure 9-B

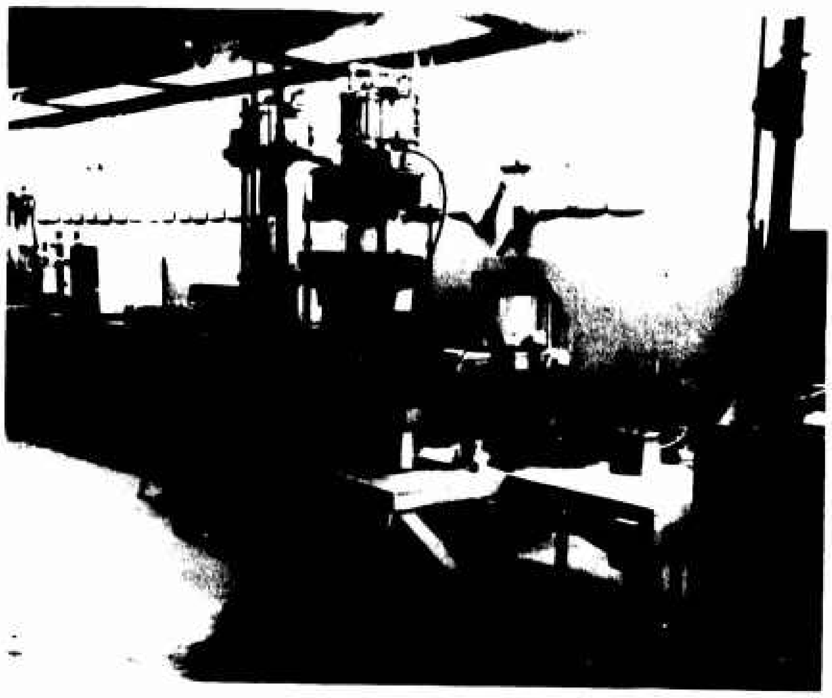


Figure 9-C

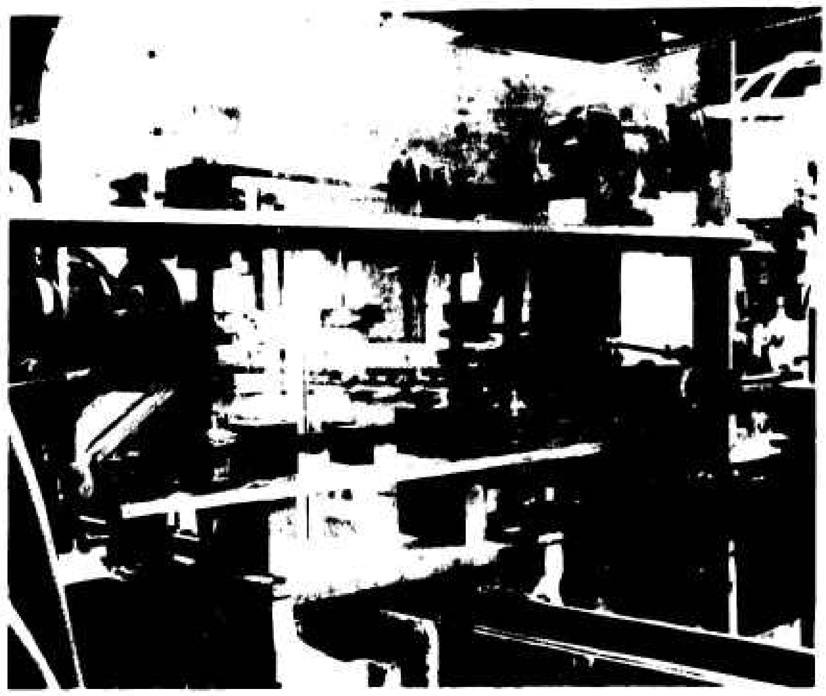


Figure 9-D

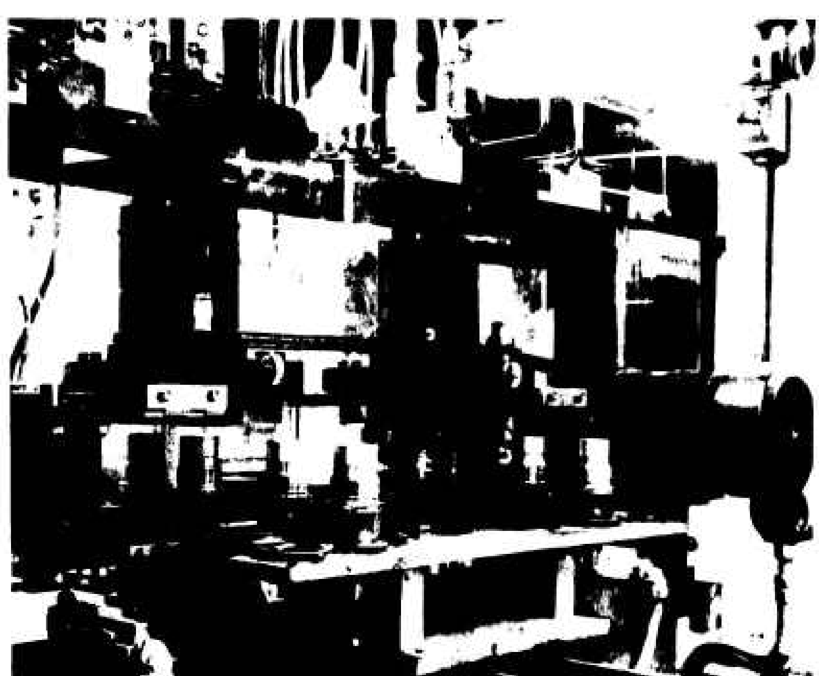


Figure 9-E

Automation of individual operations or a series of manual operations or improvement of production methods is not the only way to save money and reduce operator hazard exposure. For example, the Black Powder loading facility at LSAAP is to be completely modernized in the near future.

At present, semi-automatic or hand line loading is done on 17 items. When the modernization project is completed, most of these items will be automatically loaded and packed. All of the items will benefit in one way or another from the modernization and automation.

The project consists of two building modifications and nine new buildings. The new buildings are a receiving house, a heater house, powder drying house, powder storage magazine, primer loading building, two paint houses, a rest house, and a finished product storage and shipping house.

The modernization will include conveyorized transfer of screened and dried Black Powder to the primer loading building. There it will be automatically transferred to the primer loading machines.

Primer heads will be automatically produced in a present facility and transferred to a new rest house. When needed, they will be transferred automatically to the new primer loading building. Primer bodies will be loaded into equipment that will inspect, insert paper liners, lacquer, dry and transfer to the powder loading machine automatically.

Upon arrival of the body at the powder loading machine, it will be charged with powder, inspected for volume, the primer head will be fed onto the body, torqued, staked or crimped and the completed primer gauged and fed onto the pack-out conveyor.

Assembled primers will be packed into cardboard containers, then conveyed to the final packout bay in the storage and shipping building. Room for palletizing, if needed, is provided in this building.

Total cost of this entire project is just over $6,000,000 of which almost exactly half is for buildings and rehabilitation. The modernization and automation of the Black Powder facility at LSAAP will release 76 operators from exposure hazard. Amortization will occur in 5 years.

It is estimated now that the entire project will be ready for use 21 months after receipt of funds. The project is funded as of this date.

TRAINING AVAILABLE TO CONTRACTORS PERSONNEL RESPONSIBLE FOR HAZARDS CONTROL

Moderator:

G. W. Marsischky
Naval Ammunition Depot
Crane, Indiana

RESUME OF SPECIALIST SESSIONS
MODERATED BY MR. G. W. MARSISCHKY, CODE 043,
OF NAD CRANE, INDIANA

1. Presentations were given by Dr. John V. Grimaldi, Ph.D., of New York University, and Mr. G. W. Marsischky of the NAVORDSYSCOM Safety School.

a. Dr. Grimaldi, Director of the Center for Safety at New York University, described the course offerings currently available at NYU ranging from special classes and seminars to advanced degrees in safety. Dr. Grimaldi also expressed a willingness to develop new programs to meet existing needs if a sufficient number of persons could be expected to enter the programs. Current programs at NYU include Independent Studies, Evening Courses, Undergraduate and Graduate courses in the philosophy, principles and techniques of motor vehicle safety, industrial safety, and safety education. Typical course offerings include the following:

Foundations of Safety for the Modern Society
Industrial Safety Program: Organization, Administration and Supervision
Industrial Safety Engineering
Human Factors in Engineering Design
Accident Prevention for Motor Vehicle Fleets
Fire Prevention and Protection Inspection

Dr. Grimaldi asked that anyone interested in participating in the New York University Center for Safety's programs contact the Center directly:

The Center for Safety
New York University
Washington Square
New York, New York 10003

b. Mr. Marsischky described the course offerings of the NAVORDSYSCOM Safety School which include one and two week classes in:

Basic Explosives Hazard Control
Explosives Safety - Transportation and Storage Operations
Explosives Safety - Production Operations
Explosives Safety - Laboratory, Research and Testing Operations
Industrial Hazard Control
Systems Safety Analysis
Fire Protection
Manager's Role in Hazard Control

All of the NAVORDSYSCOM Safety School's courses are open to DOD contractor personnel on a space available basis. The basic tuition cost for DOD contractor personnel for the courses is $175 per week. However, special fees may be negotiated on a reimbursable cost basis where a significant number of persons are to be trained. Questions regarding the course schedules, tuition, participation in the program, etc., should be directed to:

Commanding Officer
Naval Ammunition Depot (Code 043)
Crane, Indiana 47522

2. The discussions following the presentations centered on the goals of the safety training programs and the need for a DOD (ASESB) recognized or sponsored explosives safety training program. Mr. Ray Myers, Director of the Army Material Command Explosives Safety Training Schcol, was present during the first session and expressed the Army Material Command's willingness to provide training for DOD contractor personnel. The general consensus of the discussions was that specific training for DOD contractor personnel was needed in the following areas:

Interpretation and Use of DOD 4145.26M, Contractors Safety Manual
Special Hazards of Explosives Production Operations
Hazard Control Management

3. Only one specific recommendation was made by the participants and that was that the ASESB should sponsor or endorse training programs in explosives safety for DOD contractor personnel.

RECENT RESEARCH RELATING TO THE DEVELOPMEMT OF
QUANTITY-DISTANCE STANDARDS

Moderator:

Dr. Thomas A. Zaker
Chief Explosives Scientist
Armed Services Explosives Safety Board

Recent Research Relating to the Development of Quantity-Distance Standards

Introduction

Adequate quantity-distance standards are an essential feature of an effective explosives safety program, inasmuch as they determine the protection provided to the general public and to operating personnel wherever concentrations of ammunition, explosives, and other hazardous materials are stored or handled.

Existing standards of the Department of Defense have evolved over years of experience with explosives incidents, supplemented by deliberate tests and analysis. As the need for storage of new materials and devices develops, the underlying technical basis of the standards must be extended, so that the resulting regulations reflect prescribed levels of protection. Furthermore, it is necessary to understand the variation of level of protection with distance for various targets, so that relative risks can be assessed adequately.

The papers presented at this session describe recent results of research programs undertaken to refine quantity-distance standards in the areas of blast and fragment effects and fire hazards. The titles and authors of the papers are as follows:

"Blast Wave Diffraction Over Barricades"
A. H. Wiedermann, IIT Research Institute, Chicago, Ill.

"Building Damage Surveys From Explosion Tests"
C. Wilton, URS Research Company, San Mateo, Calif.

"Fragment Hazards From Munition Stacks"
D. I. Feinstein & H. H. Nagaoka, IIT Research Institute

"Review of Fire Hazard Distances"
A. N. Takata, IIT Research Institute

Texts of the presentations are reprinted on succeeding pages.

BLANK PAGE

BLAST WAVE DIFFRACTION OVER BARRICADES

A. H. Wiedermann
Scientific Advisor
IIT Research Institute
Chicago, Illinois 60616

ABSTRACT

This paper describes an analytical study of blast wave diffraction over barricades. The objective of the work was to provide a theoretical basis for evaluating the effectiveness of barricades in shielding accidental explosive blast. Results of three barricade calculations, representing the near field, intraline range and far field, are presented in the form of overpressure ratio contours in the shadow region behind the barricades. Impulse ratio data and a representative overpressure waveform are given for a single revetted barricade located in the near field. It was concluded that the current standards requiring a target separation distance from an unbarricaded explosive store to be as much as twice that from a barricaded store of the same explosive quantity is unrealistic with regard to blast effects and gives credit to generally nonexistent shielding effects. In fact, for special applications the presence of a barricade may produce increased target loads.

Computer programs for both the spherically - symmetric free - air explosion problem and the two-dimensional blast diffraction problem were developed during the course of the research program.

BLAST WAVE DIFFRACTION OVER BARRICADES

INTRODUCTION

Current standards applicable to explosive processing and storage facilities require that separation distances from an unbarricaded store of mass-detonating materials be as much as twice those from a barricaded store of the same explosive quantity. There is no clear physical basis for this provision with regard to the protection afforded by a barricade against either the primary fragment hazard or the blast hazard from accidental explosion of a munition store.

Recently conducted small-charge experiments[1*] with model barricades indicate that the blast pressure field is perturbed for a distance of only a few barricade heights beyond the barricade. The zone of significant shielding depends on both the barricade design and its placement relative to the explosive source. The purpose of the presently reported work is to furnish a theoretical basis for understanding the performance and evaluating the effectiveness of barricades in shielding explosive blast.

The case of blast diffraction over a barricade surrounding an accidentally detonated explosive store can be idealized to a problem of unsteady fluid flow with rotational symmetry about a vertical axis through the center of the charge. This represents the barricade as a torus at the ground surface surrounding the charge, and limits the number of independent spatial variables to two, the radial and vertical position coordinates r and z in a meridian plane. A barricade far from the source thus approaches a straight, two-dimensional obstacle in a plane flow. The blast diffraction phenomena can be visualized then as a two-dimensional diffraction field surrounding the barricade expanding with time into an otherwise one-dimensional flow field centered about the explosive source.

COMPUTATIONAL METHODS

Various methods have been developed in recent years for the numerical solution of unsteady gasdynamic problems in two dimensions on a digital computer. The choice of method depends on both the nature of the problem to be solved and the level of detail required in the results.

---

*Superscript numerals designate appended references.

Direct finite-difference techniques utilize a device known as an artificial viscosity[2], a pressure term added to the momentum and energy equations when the compression rate is positive, in the solution of difference equivalents of the partial differential equations with respect to a finite mesh of small cells. This smears shocks typically over a few cells to preserve the continuous formulation of the problem.

In a Lagrangian difference scheme the mesh of cells is embedded in the fluid and moves with it. This is useful for multifluid problems because material interfaces are clearly resolved; however, fluid distortions must remain relatively small. In an Eulerian scheme, on the other hand, the mesh of cells is fixed in space while the fluid moves through it. Thus large fluid distortions can be accommodated, but surfaces of contact between dissimilar fluids cannot readily be resolved.

Spherical Explosion in Air

In order to obtain starting conditions for calculating the two-dimensional flow associated with diffraction of explosive blast over a barricade, a numerical solution of one-dimensional spherical blast pulse propagation from detonation of a sphere of the solid explosive pentolite (50/50 TNT/PETN) was developed. For this purpose a Lagrangian difference technique was employed.

Central difference equivalents of the equations of motion in a Lagrangian frame of reference, with initial radial distance and time as the independent variables, were integrated numerically in a one-dimensional (radial) array of cells. In this method state variables are evaluated at the cell centers, while velocities and displacements are defined at the cell boundaries. Central differencing with respect to time is secured by defining the velocity at the midpoint of each time step. In the computations, an artificial viscous pressure term quadratic in the compression rate is added to the thermodynamic pressure when the compression rate is positive.

The numerical solution proceeds from initial conditions provided by the flow profile in the detonation-product gas, called the Taylor wave, obtained by evaluation of an available similarity solution[3] for central initiation of an explosive sphere. The region in which the calculations are made is continuously extended a few cells ahead of the main air shock as it propagates outward. This process of cell addition leads to increasing storage requirements and computation time, and makes necessary periodic rezoning of the computed field as the calculation proceeds. This is accomplished by periodically halving the number of computed cells.

The numerical solution was obtained for two representations of the equation of state of the detonation-product gas. One, due to Walker and Sternberg[3] for pentolite of initial density 1.65 g/cm^3 and detonation energy release 1402 cal/g, is given by

$$p = (A_1 + A_2\rho)\ \rho e + A_3\ \rho^3 \qquad (1)$$

with

$$A_1 = 0.35$$
$$A_2 = 0.1243\ cm^3/g$$
$$A_3 = 0.01279\ megabar\text{-}cm^9/g^3$$

where p, ρ, and e are the pressure, density, and internal energy. The surrounding air was represented as a perfect gas with a ratio of specific heats $\gamma = 1.4$.

The solution for the same charge weight and energy release was also obtained with the detonation products described by the equation of state of a perfect gas with $\gamma = 1.35$, which is the low-density limit of Equation (1). In this case the air was treated as a perfect gas with a specific heat ratio of 1.35. This accounts in an approximate way for real-gas effects in the air, and makes possible application of the one-dimensional results as initial and boundary conditions in the numerical solution of blast diffraction at a near-field barricade using an Eulerian finite-difference scheme.

A comparison of the results obtained with the two representations of the equation of state is given in Figure 1, showing the paths of the main air shock and the material interface. The distance and time in Figure 1 are scaled by the cube root of the TNT equivalent of the explosive weight in a standard atmosphere. The complete solutions in both cases were stored for subsequent use in initializing the two-dimensional computed fields immediately prior to interaction of the shock with the barricade.

Explosive Blast Pulse Diffraction

To treat analytically the effect of an earth barricade on an explosive blast wave, the idealization is made to a toroidal barricade surrounding a hemispherical explosive charge at a rigid ground surface. Both the ground and barricade surfaces are assumed to be ideally reflective.

The numerical solution technique employed in the present study was originally developed at the Los Alamos Scientific Laboratory. It has been applied successfully to various shock

interaction and diffraction problems by Gentry, Martin and Daly[4] and to the transient loading of blunt obstacles by Butler[5] The present application to the diffraction of blast waves over barricades is unique in that the boundary and initial conditions on the computations are furnished by the free-air (hemispherical) explosion blast field, which varies both spatially and with time.

The equations of fluid dynamics are written with respect to the Eulerian frame of reference in which the independent variables are the cylindrical radial coordinate r and vertical coordinate z, and the time t. Conservation of mass and momentum are expressed by the relations

$$\partial\rho/\partial t + \nabla \cdot (\rho \underline{u}) = 0 \qquad (2)$$

$$\rho\partial\underline{u}/\partial t + \rho(\underline{u}\cdot\nabla)\ \underline{u} = -\nabla p \qquad (3)$$

where $\underline{u}$ is the velocity vector with components u and v in the z and r directions, respectively.

In terms of the specific total energy e_T defined by

$$e_T = e + \underline{u} \cdot \underline{u}/2 \qquad (4)$$

the energy equation for adiabatic flow without friction can be written as

$$\rho\partial e_T/\partial t + \rho(\underline{u} \cdot \nabla)\ e_T = -\nabla\cdot(p\underline{u}) \qquad (5)$$

The ideal gas equation of state applies, with $\gamma = 1.35$ for a barricade located in the near field and $\gamma = 1.4$ otherwise.

The left-hand sides of the momentum and energy equations are seen to be all of the same form. The first term in each equation is a local rate of change of the dependent variable, while the second represents convective transport of the same quantity. In the numerical scheme employed in the present study, local changes and transport effects are calculated separately in two stages of the computations at each time step.

The region through which the fluid flows is divided into a fixed mesh of rectangular cells in a meridian plane of the rotationally symmetric problem geometry. Each cell is identified by indices i and j in the z and r directions, respectively.

All properties in each rectangular cell ij, of dimensions Δz and Δr, are assumed to be known at time $t = t^n$. The computation procedure to determine the state in each cell at $t^{n+1} = t^n + \Delta t$ is as follows:

First, intermediate values of the velocity components and the energy are computed from their local rates of change neglecting the transport terms in the field equations. The pressure is modified by the addition of an artificial viscous pressure at cell boundaries across which a negative velocity gradient exists at the beginning of the time step, provided the local Mach number does not exceed a fixed value prescribed in input data. The viscous pressure term is proportional to the velocity difference between adjoining cells at the boundary where it is applied.

Next, the mass flow across cell boundaries is calculated assuming the density transported across each cell boundary to be that of the donor cell (the cell from which fluid is flowing) rather than the cell boundary average of the density. This is called donor-cell mass flow differencing. Using the mass transport so calculated, the density at t^{n+1} is obtained from the difference equivalent of the first term in Equation (2).

Finally, local changes and transport effects are summed to obtain the values of u, v and e_T at the end of the time step, and the pressure p is obtained from the equation of state. The next time step Δt is determined from a Courant-type stability condition:

$$\Delta t = \frac{1}{2} \text{Min} \left[\frac{\text{Min}(\Delta z_i, \Delta r_j)}{\text{Max}(u_{ij}, v_{ij}, c_{ij})} \right] \tag{6}$$

where c_{ij} is the sound speed in cell ij.

The two types of boundaries that occur in exterior flow problems of this type are reflective surfaces and continuative boundaries. The first represent rigid surfaces at which the normal velocity component and pressure gradient vanish. Continuative boundaries, on the other hand, appear as surfaces in the fluid medium chosen to limit the extent of the computing mesh; flow may occur across such boundaries.

During the early stages of blast diffraction, the continuative boundary conditions are prescribed by the free-air explosion solution and ambient air conditions. Specification of these data in a control zone three cells in thickness at each continuative boundary permits the assignment of state variables and their gradients in sufficient detail to be compatible with two-dimensional calculations in the enclosed computed field. To avoid introducing extraneous reflected signals into the region of interest, the continuative boundaries were kept sufficiently far removed by zoning the computed

field nonuniformly, with resolution decreasing away from the immediate vicinity of the barricade. A typical grid configuration is presented in Figure 2.

Computations were performed in terms of dimensionless variables involving the cube root of the charge weight. However, a given barricade geometry is defined by at least two independent cross-sectional dimensions (height and crest width) in addition to the distance from the source. Therefore some care must be exercised in applying the computed results to widely different charge weights, since the scaling laws for blast imply conditions of strict geometric similarity.

DISCUSSION OF RESULTS

Four barricade shock diffraction calculations were made corresponding to the following configurations:

- Single-revetted barricade at 2.5 ft/lb$^{1/3}$ with vertical face toward the explosive source
- Mound barricade at 2.5 ft/lb$^{1/3}$
- Single-revetted barricade at 9 ft/lb$^{1/3}$ with the vertical face toward the explosive source
- Single-revetted barricade at 40 ft/lb$^{1/3}$ with the vertical face away from the explosive source.

All of the above barricades have the same height and crest width, 0.5 and 0.075 ft/lb$^{1/3}$, respectively, and the inclinations of their sloping faces are all 2.5. Partial results of three of these calculations are summarized herein.

Review of Shock Diffraction Phenomena

In order to better interpret the results of the present numerical calculations, discussion of the shock interaction is presented.

This is accomplished by examining an interferometric photograph[6] of a flow at the time the incident shock front has just passed the top of a mount-shaped obstacle. Figure 3 presents a schematic representation of the interferometric photograph showing contours of constant overpressure ratio as well as various wavefronts.

At an earlier time the incident shock interacted with the front slope of the mound, and a localized high pressure zone was created at this surface. This region was bounded

in part by a reflected shock that propagates away from the obstacle. The reflected and incident waves may coalesce to form a Mach stem bounding the front of this region. At the later time shown by the figure, the wavefront contacting the mound surface has diffracted around its crest.

A rarefaction wavefront propagates back into the reflected high pressure region resulting in a lower pressure in the neighborhood of the crest. Due to the sharp corner of the crest a vortex of extremely low central pressure is produced which then slowly migrates into the region behind the mound while it grows in size. At a later time, the diffracted shock will interact with the level surface behind the mound and another high pressure region is thereby created. This high pressure region expands upward and outward behind this second reflected shock. A complex flow field is established as these primary disturbance fronts interact with each other and the reflective surfaces. The fluctuations in this region are continually weakened and diffused until it approaches a quiescent state.

Figure 4 presents a contour plot showing curves of constant overpressure ratio corresponding to the experimental series associated with Figure 3. The normalizing factor used was the overpressure of the incident step wave. Also illustrated by Figure 4 are the regions where the maximum pressure are caused by the various interaction mechanisms discussed above. In regions I and II the maximum pressure is due to reflection of the incident wave; in region III, the combined effect of the reflected shock and rarefaction wave; in region IV, the diffraction process; and in region V, the reflection of the diffracted shock.

Of particular interest is the region having an overpressure ratio smaller than unity, depicted in Figure 4 as the shadowed zone. Within this zone the lowest value attained is 0.55 at the central portion of the back surface. The contours that extend into this zone increase as the distance from the obstacle increases. Thus significant overpressure reductions are seen to occur only in the immediate vicinity of the obstacle. The overpressure ratios along the level surface behind the obstacle are slightly larger than unity in this particular case.

Results of the Numerical Calculations

The shielding effectiveness of barricades is determined by comparing the results obtained in the shadow region with a barricade present to the results that would be obtained

without a barricade. The former results are obtained from the two-dimensional barricade calculations, while the latter can be obtained by either a full two-dimensional treatment with no barricade present or by the one-dimensional free-air solution. In the near field region, these two methods of computing the spherically-symmetric blast wave yield results which, although qualitatively similar, differ somewhat quantitatively due to the different calculational methods. The proper reference is that provided by the two-dimensional treatment since both the barricaded and unbarricaded solutions would then be subjected to the same numerical procedure. For the intraline and far field regions, the one-dimensional computational treatment is adequate. The results are presented graphically and include overpressure waveforms, peak overpressure ratio contours, and measurement of positive phase impulse.

A comparison between free-air waveforms computed at the same near-field distance by the two-dimensional method and by the more precise one-dimensional calculation is given in Figure 5. The difference in peak overpressure calculated by the two methods is due to the finer mesh resolution possible in the simpler one-dimensional problem.

A typical overpressure waveform in the shielded region behind a near-field barricade is compared with the corresponding unbarricaded result in Figure 6. The extent of the shielding effect of the near-field barricade is shown in the contour map of Figure 7. It may be noted that along the ground surface the overpressure never drops below 90 percent of the unbarricaded value. A comparison of impulses at selected points in this problem are presented in Figure 8 and show that not more than a 30 percent reduction below unbarricaded values occurs. This is consistent with impulse measurements in a near-field barricade experiment[1].

Similarly, for a barricade at intraline range (9 ft/lb$^{1/3}$) the contours of overpressure ratio in Figure 9 show the extent to which the barricade provides some measure of shielding. The overpressure ratios along the ground behind the barricade are always equal to or slightly greater than unity. The lowest computed value of the overpressure ratio was 0.72 in this problem.

Finally, in the case of a far-field barricade, the contour map of Figure 10 shows that, with the exception of a small region near the rear edge of the barricade, the shielding effects are very small.

CONCLUSIONS

The accuracy of target response calculations to blast loading is of the order of 10 percent or more. Therefore, a barricaded to unbarricaded maximum overpressure or positive phase impulse ratio of 0.8 or less provides a reasonable criterion of effective blast shielding.

Applying this criterion in each of the four cases presented, we conclude that the barricades considered are not effective in affording protection from blast effects for general target applications. This is particularly true for targets near the ground.

There are regions of effective shielding, but these typically begin in the vicinity of the barricade backside and extend upward and outward beyond the barricade. Thus, some very special applications may exist for which this limited shielding effect is useful.

These conclusions are in general agreement with the limited experimental information currently available.

The current standards requiring a target separation distance from an unbarricaded explosive store to be as much as twice that from a barricaded store of the same explosive quantity is unrealistic with regard to blast effects and gives credit to generally nonexistent shielding effects. In fact, for special applications the presence of a barricade may produce increased target loads.

ACKNOWLEDGEMENTS

This study was performed under Contract DAHC04-70-C-0013 for the Armed Services Explosive Safety Board, supervised by Mr. R. G. Perkins, Safety Engineer, and Dr. T. A. Zaker, Chief Explosives Scientist.

Several IIT Research Institute staff members contributed significantly to this work. Mr. T. V. Eichler performed the computer programming, while the author assisted in the interpretation of the results. Dr. T. A. Zaker (formerly Science Advisor, IITRI) directed the initial stages of this work.

REFERENCES

1. Wenzel, A. B., et al, "Barricaded and Unbarricaded Blast Measurements," Southwest Research Institute, Subcontract 1-00-431, Contract DAHC04-69-C-0028, October 1969.

2. von Neumann, J. and Richtmyer, R. D., "A Method for the Numerical Calculation of Hydrodynamic Shock," J. Appl. Phys. 21, 232.

3. Gentry, R. A., Martin, R. E. and Daly, B. J., "An Eulerian Differencing Method for Unsteady Compressible Flow Problems," J. Comp. Phys. 1, 87-118, (1966).

4. Walker, W. A. and Steinberg, H. M., "The Chapman - Jouguet Isentrope and the Underwater Shockwave Performance of Pentolite," Proceedings, Fourth Symposium on Detonation Vol. 1, B156-B169, NOL (October 1965).

5. Butler, T. D., "Numerical Calculation of the Transient Loading of Blunt Obstacles by Shocks in Air," AIAA J., Vol. 4, No. 3 (March 1966).

6. Bleakney, W., "The Diffraction of Shock Waves Around Obstacles and the Transient Loading on Structures," Technical Report II-3, NR061-020, Princeton University, March 1950.

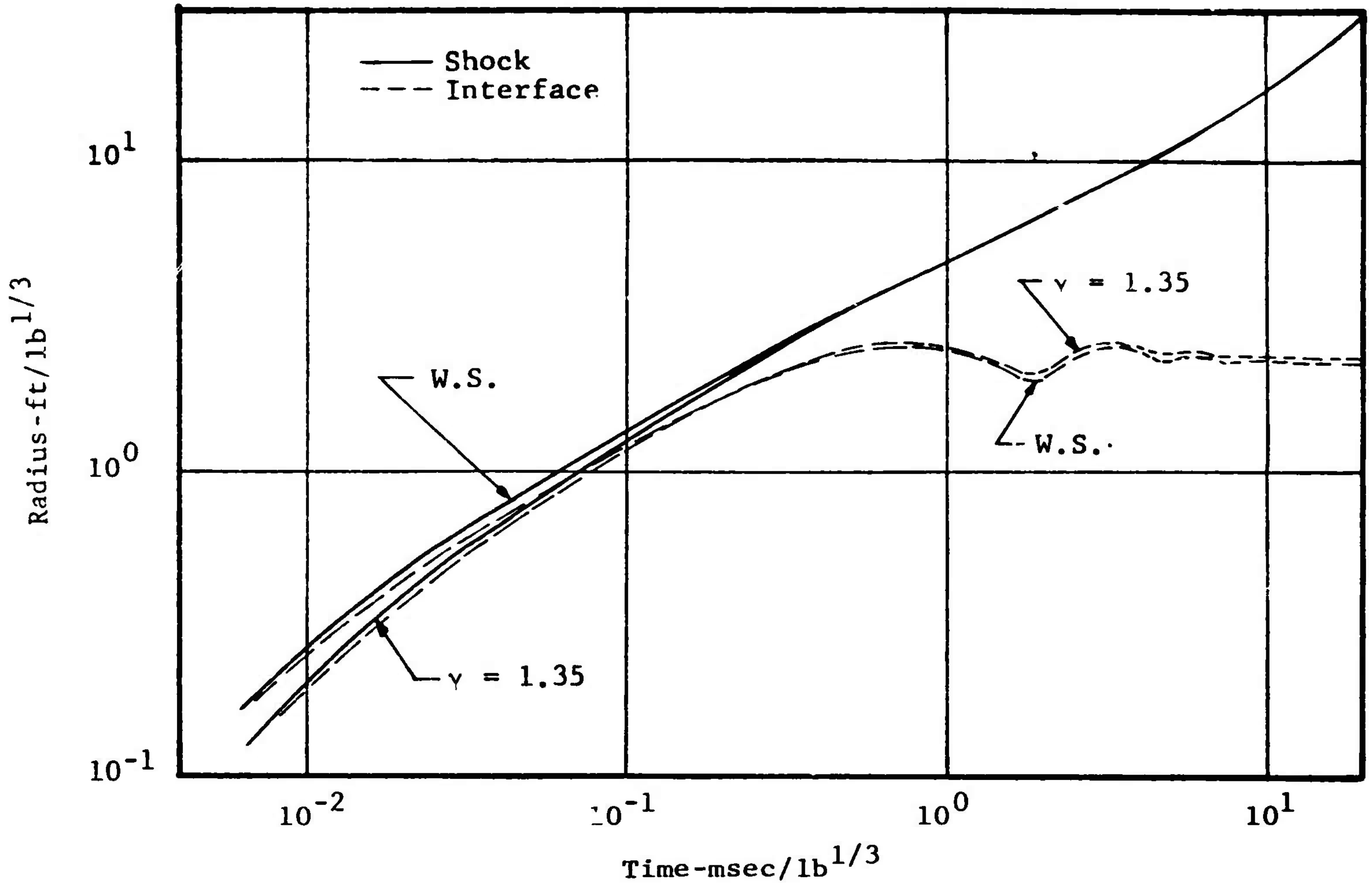


Figure 1 Air Shock and Interface Paths for Walker-Sternberg (W.S.) and Ideal Gas (γ = 1.35) Models of Pentolite Detonation Products

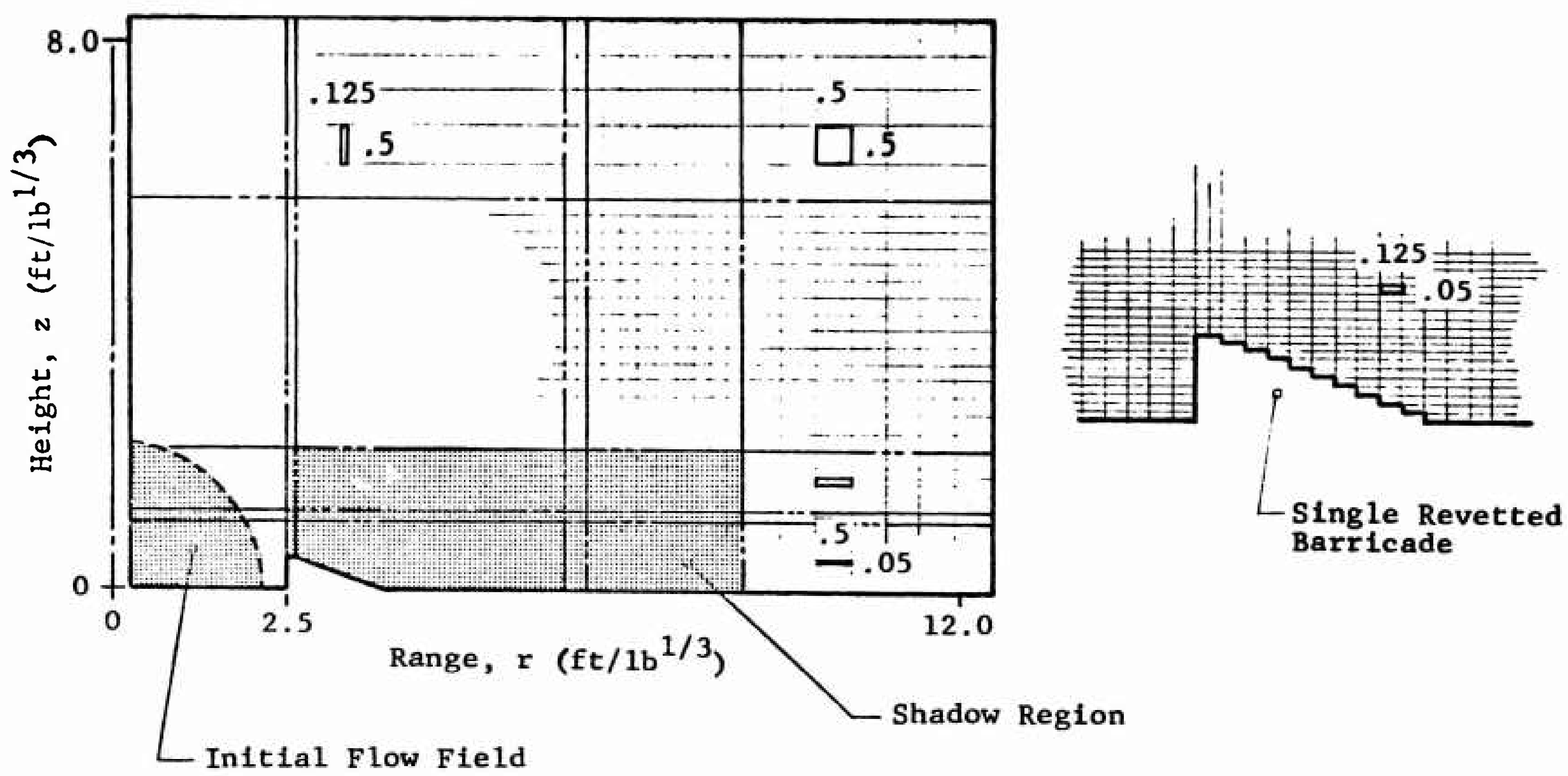


Figure 2 Grid and Boundary Configuration for Barricade Problem

Shock Overpressure = 13.5 psi
Wave Duration = ∞

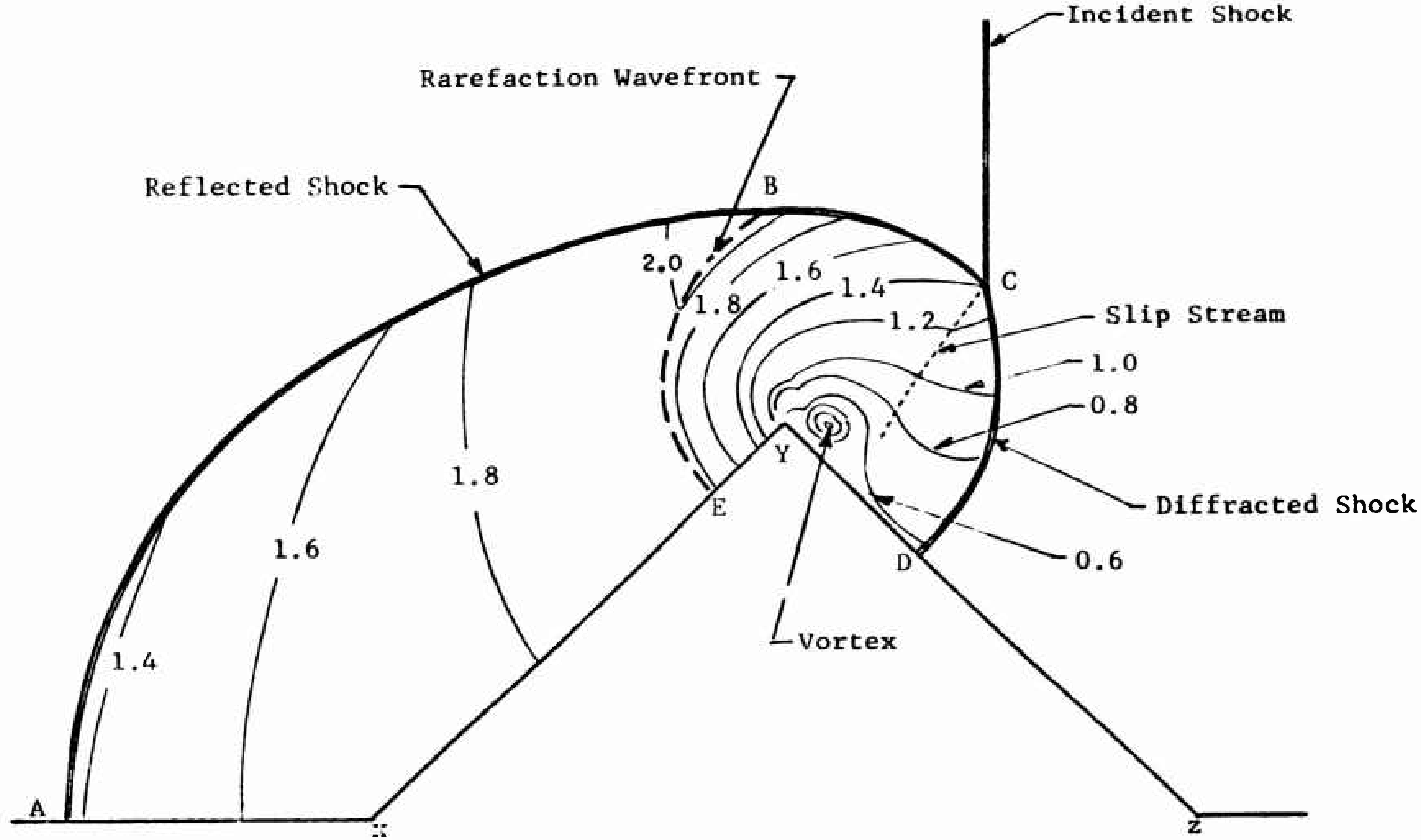
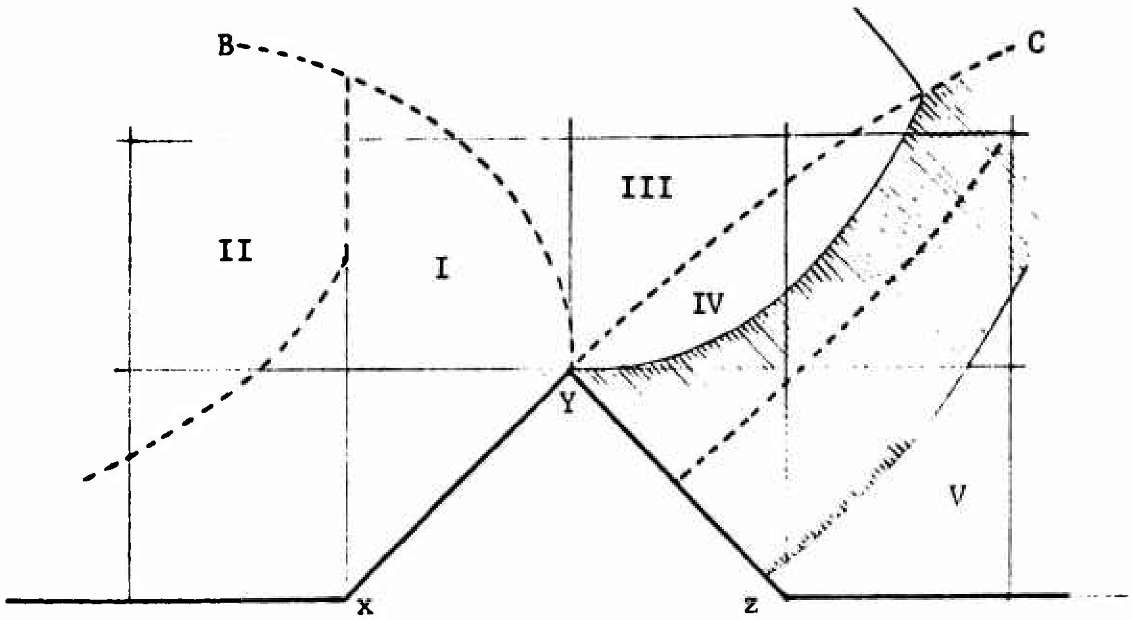
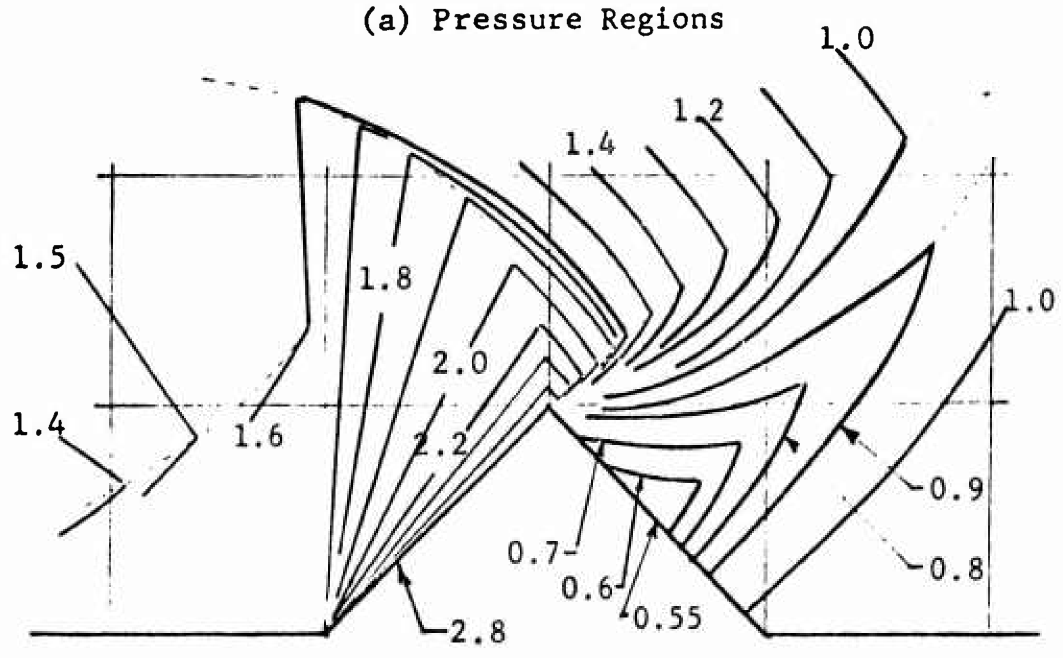


Figure 3 Shock Interaction with Mound Barricade-Princeton Interferometric Data



(a) Pressure Regions



(b) Maximum Pressure Contours

Figure 4 Peak Pressure Contours for Mound Barricade-Princeton Interferometric Data

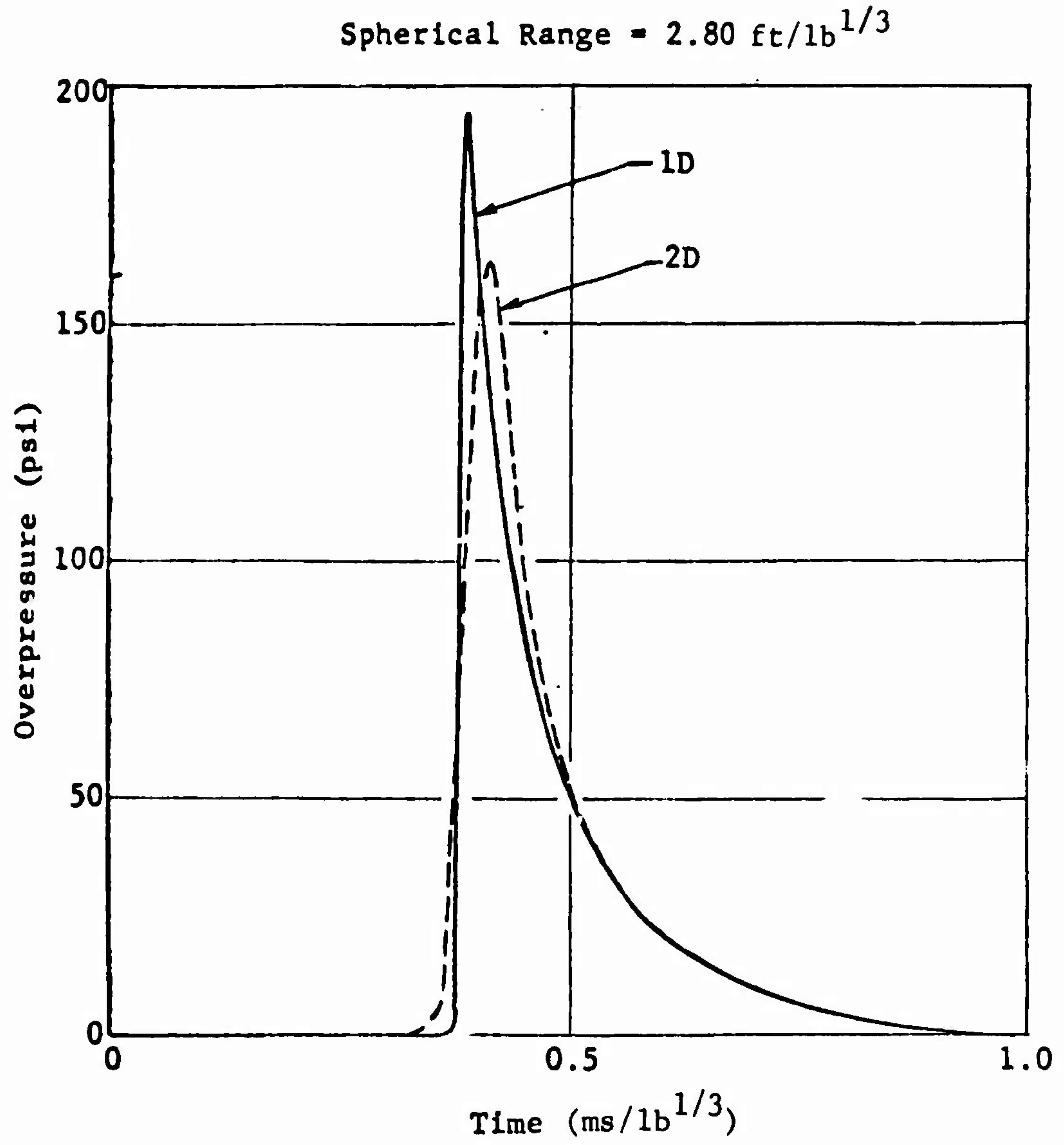


Figure 5 Comparison of Free Field Wave Forms

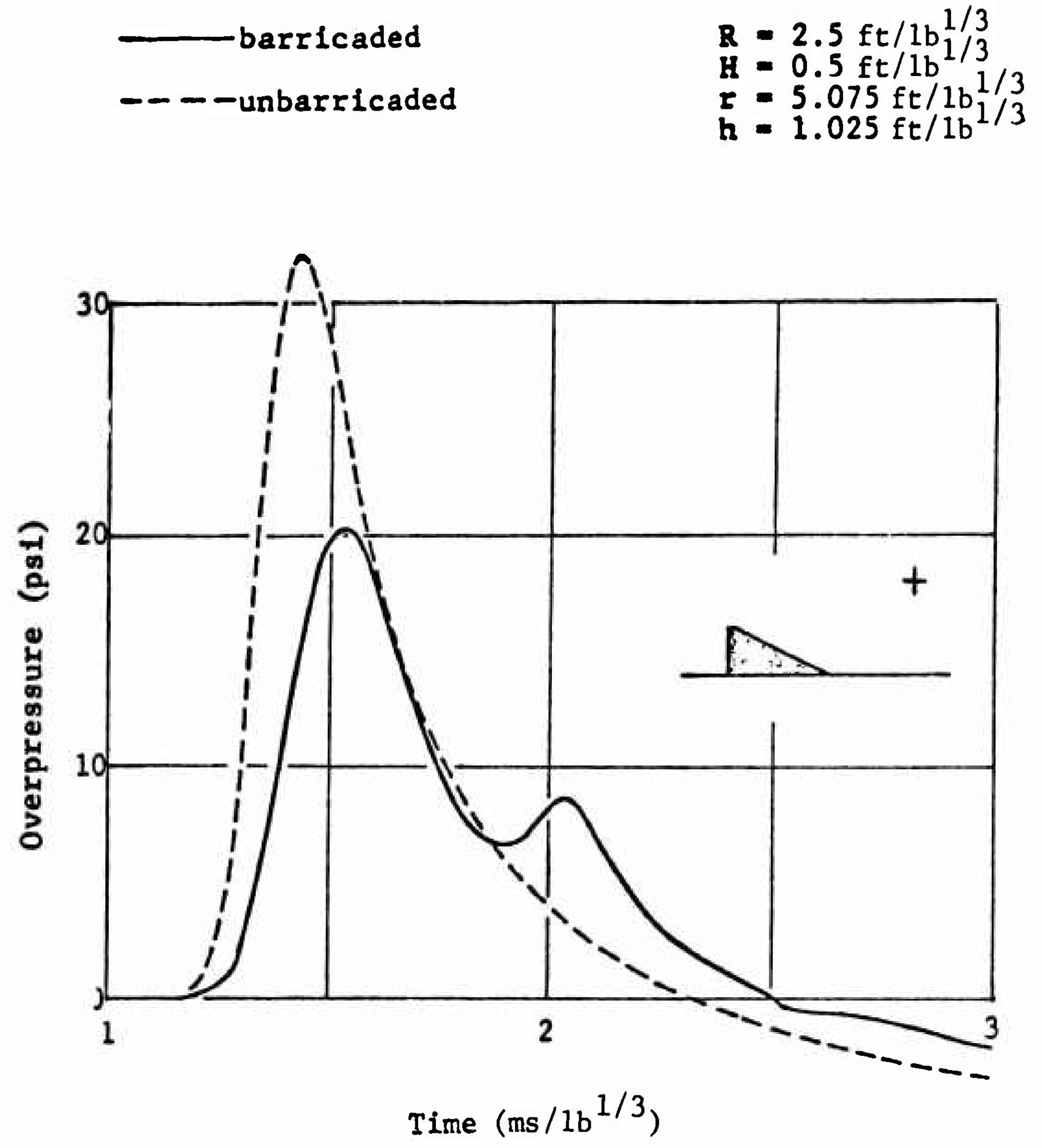


Figure 6 Pressure Wave Forms-S. R. Barricade at 2.5 ft/lb$^{1/3}$

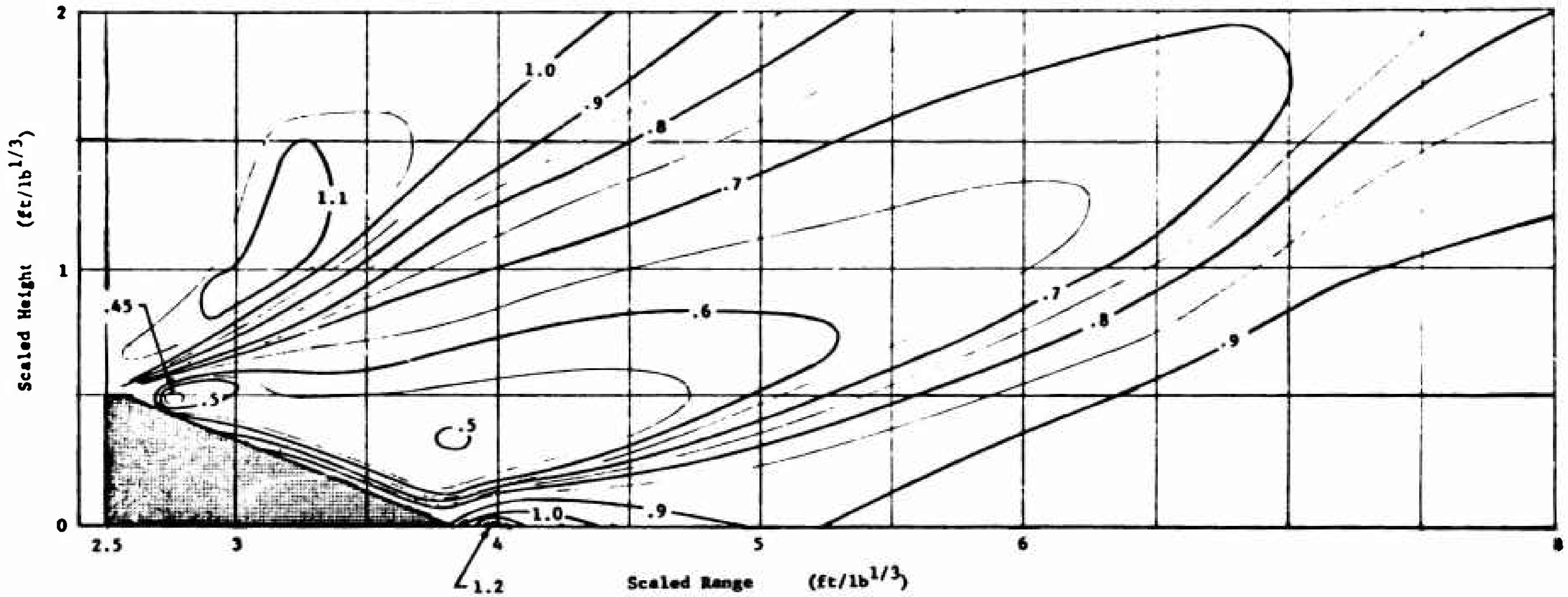


Figure 7 Overpressure Ratio Contours - S. R. Barricade at 2.5 $ft/lb^{1/3}$

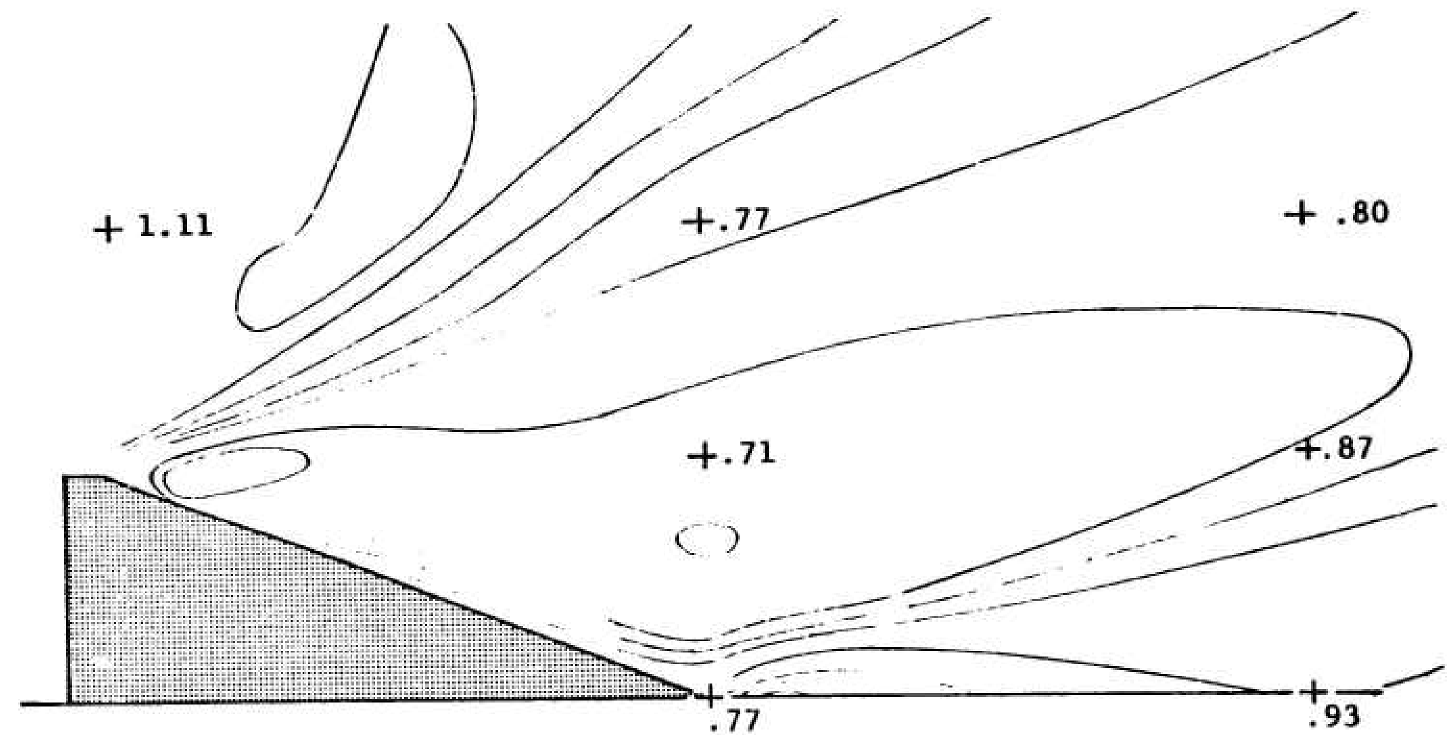


Figure 8 Impulse Ratio-S. R. Barricade at 2.5 ft/lb$^{1/3}$

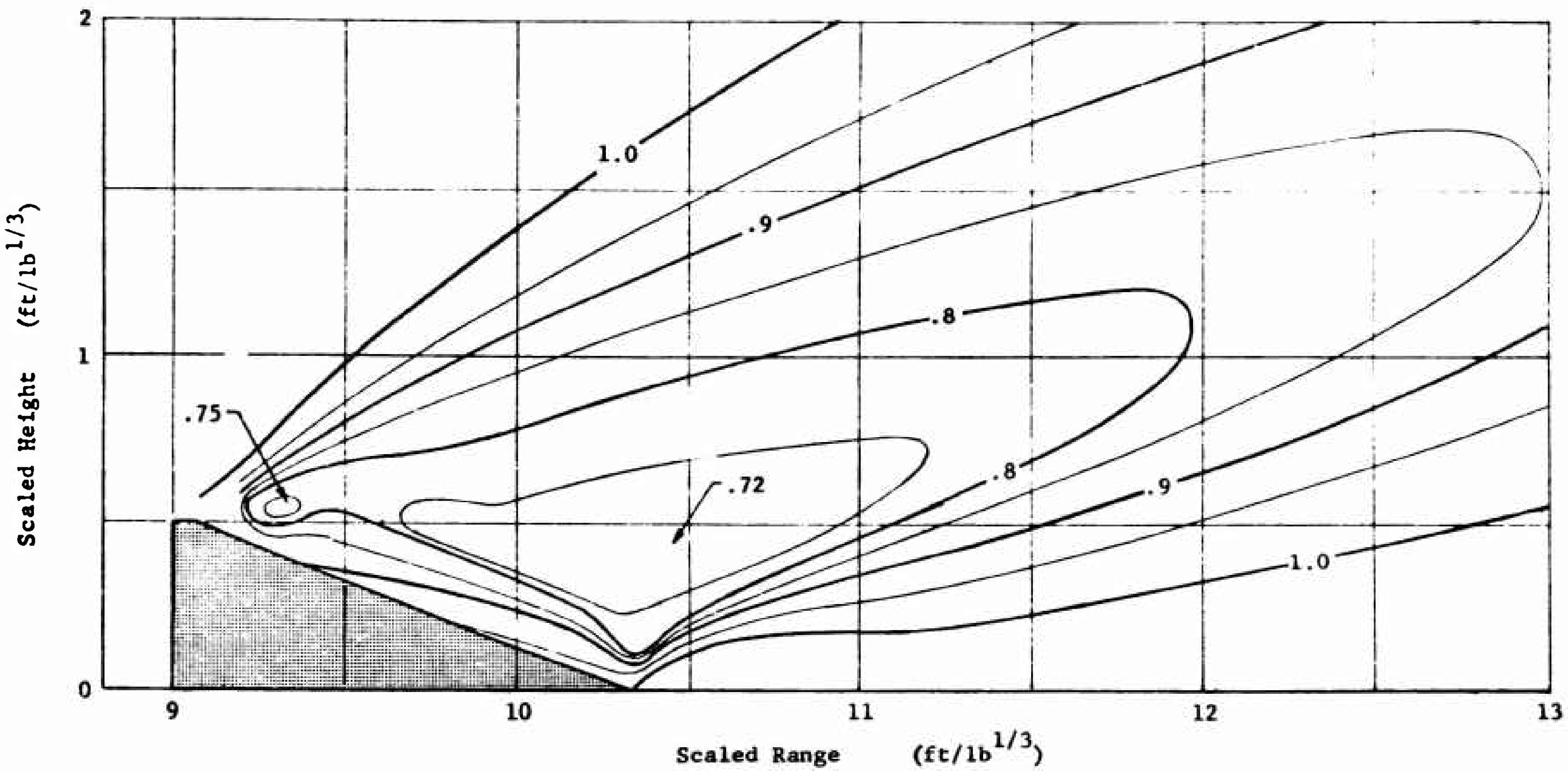


Figure 9 Overpressure Ratio Contours - S. R. Barricade at 9 ft/lb$^{1/3}$

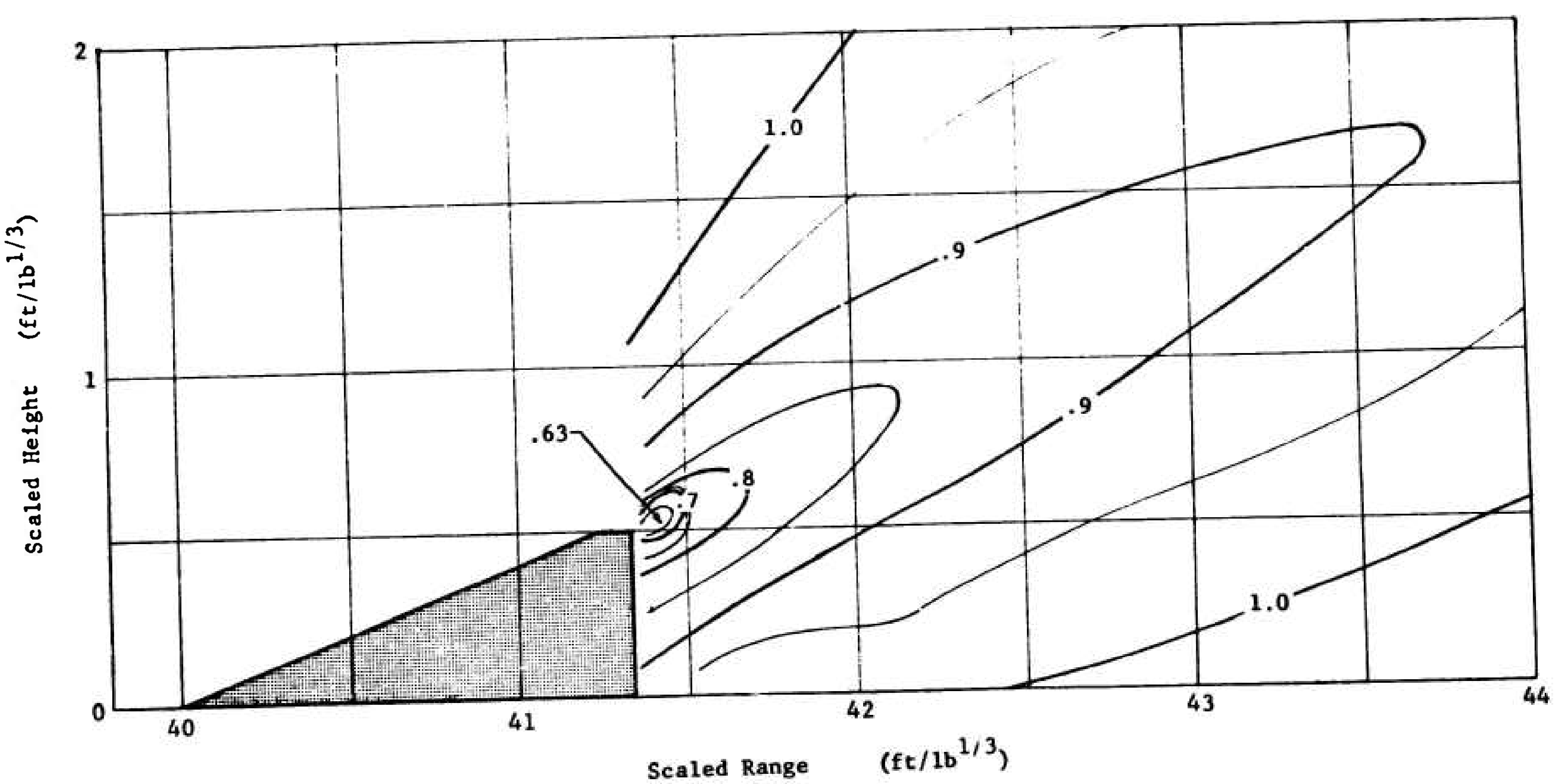


Figure 10 Overpressure Ratio Contours - S. R. Barricade at 40 ft/lb$^{1/3}$

BLANK PAGE

BUILDING DAMAGE SURVEYS FROM EXPLOSION TESTS

C. Wilton
URS Research Company
San Mateo, California

Introduction

For many years the quantity-distance regulations for the separation between potential explosion sources and sites to be protected have been based on empirical data derived from accidental explosions. Recently, a series of tests was conducted, by the Armed Services Explosive Safety Board (ASESB) and the Defense Atomic Support Agency (DASA), to obtain experimental test data to aid in the verification of these quantity-distance regulations. In these tests, wood-frame houses were exposed to shock waves from high explosive charges, with the incident overpressure at the test houses being somewhat larger than those implied in the regulations covering inhabited building quantity-distance relationships for unbarricaded charges. Another purpose of the tests was to investigate the effect of charge size or pulse duration on structural damage.

Tests which were conducted in this series included: two tests at the Naval Weapons Center (NWC), China Lake (Ref. 1), one of which used a single 10,000-lb hemispherical charge exposing a test house to a peak incident overpressure of 0.9 psi, and the second of which used two 5,000-lb hemispherical charges detonated 24 milliseconds apart exposing the test house to a peak incident overpressure of 1.1 psi; the 500-ton Prairie Flat event in which a test house was exposed to approximately 1 psi (Ref. 2); a 100-ton Ammonium Nitrate/Fuel Oil (AN/FO) test which exposed a test house to a peak incident overpressure of 1.6 psi; and the recent Dial Pack event in which a test house was exposed to a peak incident overpressure of approximately 2.6 psi from the explosion of 500 tons of TNT.

The purpose of this paper is to summarize the data from these tests and to compare these data with the results from a Nuclear Weapon test in which a house was exposed to a peak incident overpressure of 1.7 psi.

Explosive parameters and peak incident overpressures at the test houses for all the tests are summarized in Table 1.

Table 1

SOURCES OF DATA

TEST	EXPLOSIVE	CHARGE SIZE	OVERPRESSURE (PSI)
N.W.C. #1	TNT	10,000-lb	0.9
N.W.C. #2	TNT	2-5,000-lb	1.1
AN/FO	Ammonium Nitrate/ Fuel Oil	100-ton	1.6
PRAIRIE FLAT	TNT	500-ton	1
DIAL PACK	TNT	500-ton	~ 2.6
UPSHOT KNOTHOLE	Nuclear	16.4-kt	1.7

Test House

The frame house, used for all these tests, was a conventional two-story house -- 33 ft 4 in. long by 24 ft 8 in. wide with full basement and gabled roof. The house had three rooms on each floor and a brick fireplace in the living room. This house was built in accordance with the Office of the Chief of Engineers, Department of the Army, Drawing No. 60-08-45. Floor plans of this house are shown in Fig. 1.

House Damage

The damage experienced by the test houses in the six tests varied considerably. In all the tests, window destruction on the front sides of the houses (that side facing the blast) was virtually complete. On the sides of the houses, window destruction varied from about 50% for the low incident overpressure tests to 100% for the higher incident overpressure tests, and on the back side window destruction ranged from zero percent to 100%. Similarly, stud and roof rafter damage ranged from virtually none broken to a significant number broken, and ceiling and wall plaster damage ranged from an insignificant amount to virtually complete damage in certain portions of the house.

In Fig. 2 is shown an exterior view of one of the houses which suffered relatively little damage, and in Fig. 3 one of the houses which suffered most extensive damage. Except for apparent window and door damage, the first house (exposed to 0.9 psi peak incident overpressure from a 10,000-lb charge at NWC) appears virtually intact. Far more extensive damage can be seen on the second house (exposed to 2.6 psi from a 500-ton charge at Dial Pack), with one window frame being blown out, the siding on both upper and lower floors showing obvious damage, and the roof being clearly dished and separated at the peak.

Typical of the damage experienced on the Dial Pack test is that of the studding near a first story window frame shown in Fig. 4. Roof rafter breakage from the AN/FO test at an incident overpressure of 1.6 psi is shown in Fig. 5.

The extent of house damage experienced during the six tests is summarized in Tables 2 through 7.

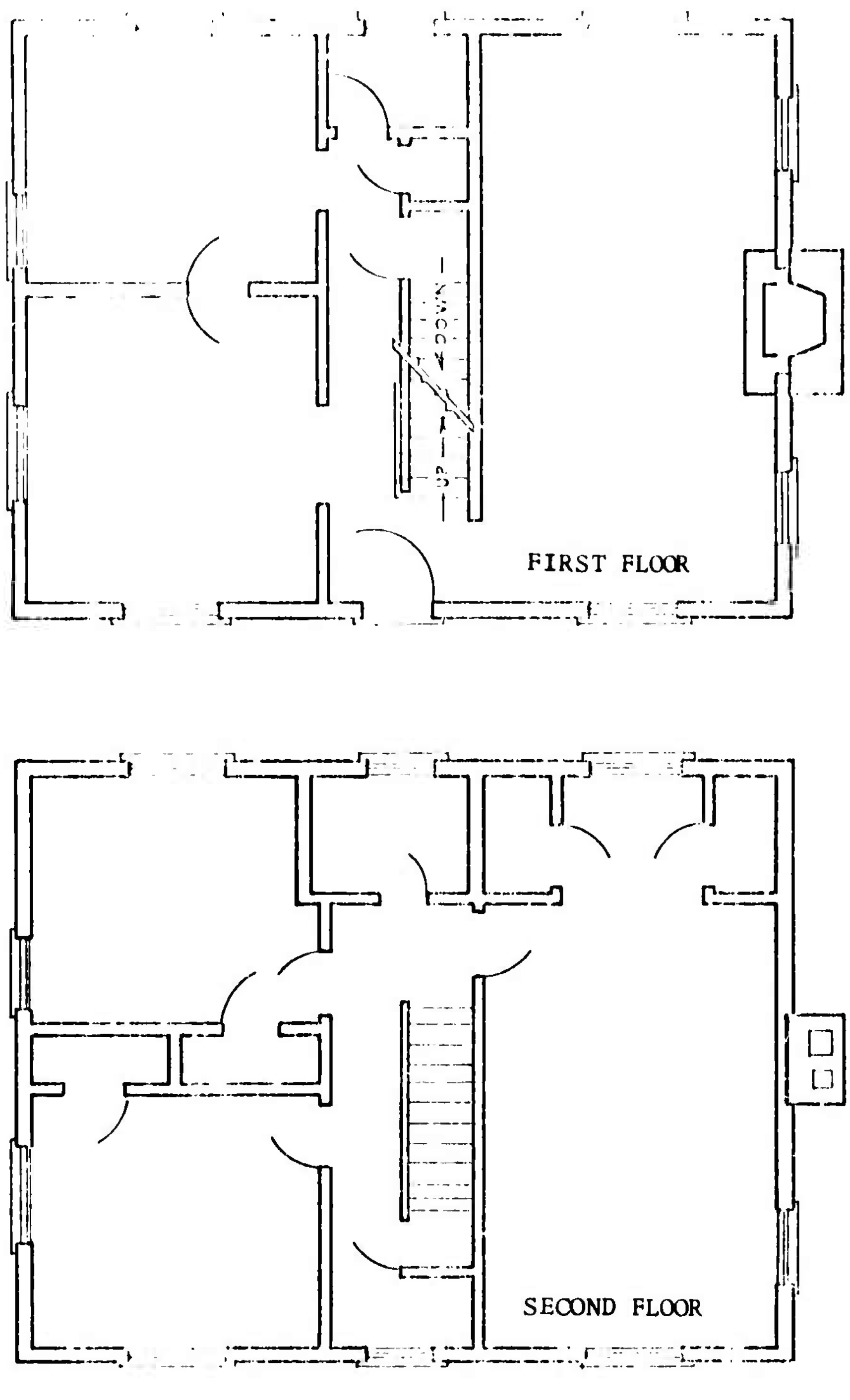


Fig. 1. Floor Plan of Test House

Fig. 2 EXTERIOR VIEW OF HOUSE EXPOSED TO 0.9 psi PEAK OVERPRESSURE FROM A 10,000 LB CHARGE AT NWC

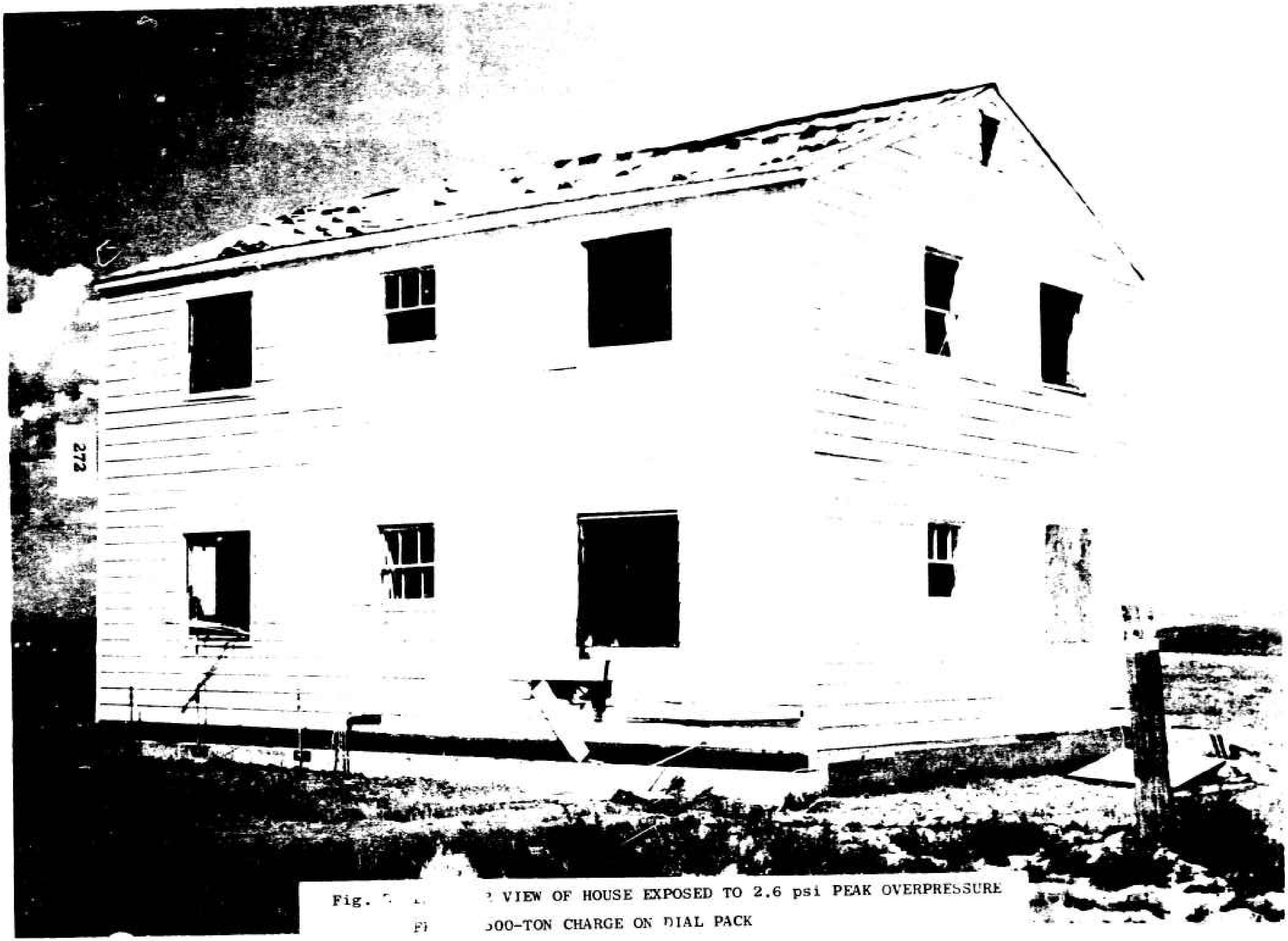


Fig. [illegible] VIEW OF HOUSE EXPOSED TO 2.6 psi PEAK OVERPRESSURE
F[illegible] 500-TON CHARGE ON DIAL PACK

Fig. 4 STUDDING DAMAGE ON FIRST FLOOR AFTER DIAL PACK TEST

Fig. 5 ROOF RAFTER BREAKAGE AFTER AN/FO TEST

Table 2

DAMAGE FROM N.W.C. TEST #1

CHARGE SIZE 10,000-lb TNT

OVERPRESSURE - psi 0.9

- WINDOWS (% Destroyed)

  Front 90 Left 55 Right 30 Rear 2

- STUDS (Number Broken) - 0

- ROOF RAFTERS (Number Broken)

  Front 0 Rear 0

- CEILING PLASTER (% Destroyed)

  1st Floor 0 2nd Floor 0

- WALL PLASTER (% Destroyed)

  1st Floor 5 2nd Floor 5

Table 3

DAMAGE FROM N.W.C. TEST #2

CHARGE SIZE 2-5,000-lb TNT

OVERPRESSURE - psi 1.1

- WINDOWS (% Destroyed)

  Front 98 Left 70 Right 55 Rear 20

- STUDS (Number Broken) - 0

- ROOF RAFTERS (Number Broken)

  Front 1 Rear 0

- CEILING PLASTER (% Destroyed)

  1st Floor C 2nd Floor 2

- WALL PLASTER (% Destroyed)

  1st Floor 7 2nd Floor 7

Table 4

DAMAGE FROM PRAIRIE FLAT TEST

CHARGE SIZE 500 ton

OVERPRESSURE - psi 1

- WINDOWS (% Destroyed)
  Front 100 Left 80 Right 10 Rear 0
- STUDS (Number Broken) - 6
- ROOF RAFTERS (Number Broken)
  Front 19 Rear 0
- CEILING PLASTER (% Destroyed)
  1st Floor 0 2nd Floor 15
- WALL PLASTER (% Destroyed)
  1st Floor 13 2nd Floor 12

Table 5

DAMAGE FROM AN/FO TEST

CHARGE SIZE 100 ton

OVERPRESSURE - psi 1.6

- WINDOWS (% Destroyed)

  Front 100 Left 20 Right 100 Rear 0

- STUDS (Number Broken) - 12

- ROOF RAFTERS (Number Broken)

  Front 23 Rear 1

- CEILING PLASTER (% Destroyed)

  1st Floor 0 2nd Floor 20

- WALL PLASTER (% Destroyed)

  1st Floor 15 2nd Floor 16

Table 6

DAMAGE FROM DIAL PACK TEST

CHARGE SIZE 500 ton

OVERPRESSURE - psi 2.6

- WINDOWS (% Destroyed)
  Front 85 Left 100 Right 100 Rear 1
- STUDS (Number Broken) - 67
- ROOF RAFTERS (Number Broken)
  Front 2 Rear 23
- CEILING PLASTER (% Destroyed)
  1st Floor 0 2nd Floor 100
- WALL PLASTER (% Destroyed)
  1st Floor 50 2nd Floor 50

Table 7

DAMAGE FROM UPSHOT KNOTHOLE TEST (NUCLEAR)

CHARGE SIZE 16.4 kt

OVERPRESSURE - psi 1.7

- WINDOWS (% Destroyed)
  Front 100 Left 100 Right 100 Rear 50
- STUDS (Number Broken) - ~16
- ROOF RAFTERS (Number Broken)
  Front 23 Rear 2
- CEILING PLASTER (% Destroyed)
  1st Floor 0 2nd Floor ~2
- WALL PLASTER (% Destroyed)
  1st Floor ~6 2nd Floor ~8

Damage Comparisons

It is difficult if not impossible to rank damage -- in any quantitative way -- from tabulations such as those shown in Tables 2 through 7. It is clear that the damage shown in Table 6 (to a house which experienced 2.6 psi peak incident overpressure from a 500-ton burst) is greater than that shown in Table 2 (to a house which experienced 0.9 psi from a 10,000 lb burst) but how much greater the damage is cannot be simply deduced. Similarly, it is not immediately obvious that the damage shown in Table 6 is significantly greater than that in Table 7 (to a house which experienced 1.7 psi from a 16.4 kiloton nuclear burst.)

However, a simple, pragmatic method to make quantitative damage comparisons has been developed, and in the remainder of this section the method will be described, and preliminary results of its application will be given.

The method is a cost oriented one, and requires first that plans for a structure being considered be examined in some detail to determine the relative costs of its various elements. This has been done approximately for the house used in the six tests, with the results shown in Table 8. Estimates are then made of the total cost of construction of the building, (which can vary from region to region) through discussions with contractors, knowledge of construction practices and labor rates in an area, etc. This information, along with that in Table 8 makes it possible to assign specific costs to the various structural elements shown in Table 8.

The final step can be done in one of two ways: either the damage cost can be estimated from observed damage (for example, 80% of windows were destroyed; windows account for 6% of the building cost; therefore the cost of window damage is 4.8% of the total building cost); or the repair cost can be estimated by assessing the cost of removing and replacing damaged elements. The latter parameter -- repair costs -- is considered to be more meaningful a measure than damage costs.

For the six tests under discussion, preliminary estimates have been made of both damage and repair costs (in terms of percentage of total

Table 8

RELATIVE COST OF HOUSE ELEMENTS

ITEM	% TOTAL COST
● EXCAVATION, FOUNDATION BASEMENT	20%
● FLOOR JOISTS & FLOORING	10
● WALL FRAMING	11
● ROOF	7
● EXTERIOR WALLS	12
● INTERIOR WALLS	21
● DOORS	4
● WINDOWS	6
● MISCELLANEOUS - Stairs, Fireplace, Paint, Trim	9

building costs). These are plotted on Fig. 6 as a function of peak incident overpressure; both curves have been extended to zero cost for zero peak incident overpressure. Included on that figure is some preliminary information from a house in the UPSHOT-KNOTHOLE series which experienced about 5 psi overpressure, and was virtually destroyed including part of the foundations.

It is clear that there is a strong correlation of both damage and repair costs with peak incident overpressure, though the variability -- seen at the lower end of the overpressure range - was significant.

Though it has not yet been done, it would appear that correlation with either total impulse or duration would be much less satisfactory. For the three tests which gave peak overpressures of about 1 psi, impulse or duration should vary by a factor of about 4.5, far greater than the variability in costs for these tests, and for the two tests which gave peak overpressures of about 1.6 psi, impulse or duration should vary by a factor of about 5.5, again far greater than the observed cost variability.

It should be noted that Fig. 6, along with previously measured results from barricaded and unbarricaded charge geometries confirm the desirability of eliminating the quantity-distance "credit" given to barricaded charge geometries over unbarricaded geometries. The basic "safe" scaled inhabited building distance (actual distance divided by the cube root of the charge weight) is currently 80 $ft/lb^{1/3}$ a scaled distance which would give rise to an overpressure of about 0.5 psi. In DOD Instruction 4145.23 this distance can be halved if barricades are employed. In Ref. 5 it was shown that overpressures at inhabited building distances are actually greater from barricaded charge geometries than for unbarricaded geometries (although closer to the charge -- at intermagazine distances -- the reverse is true). Even assuming equality of overpressures at inhabited building distances from the two geometries, the 40 $ft/lb^{1/3}$ scaled distance permitted for barricaded geometries should give rise to about 1.2 psi at a structure. From Fig. 6, repair costs at this overpressure should amount to about 25% if the structure resembled the test house employed.

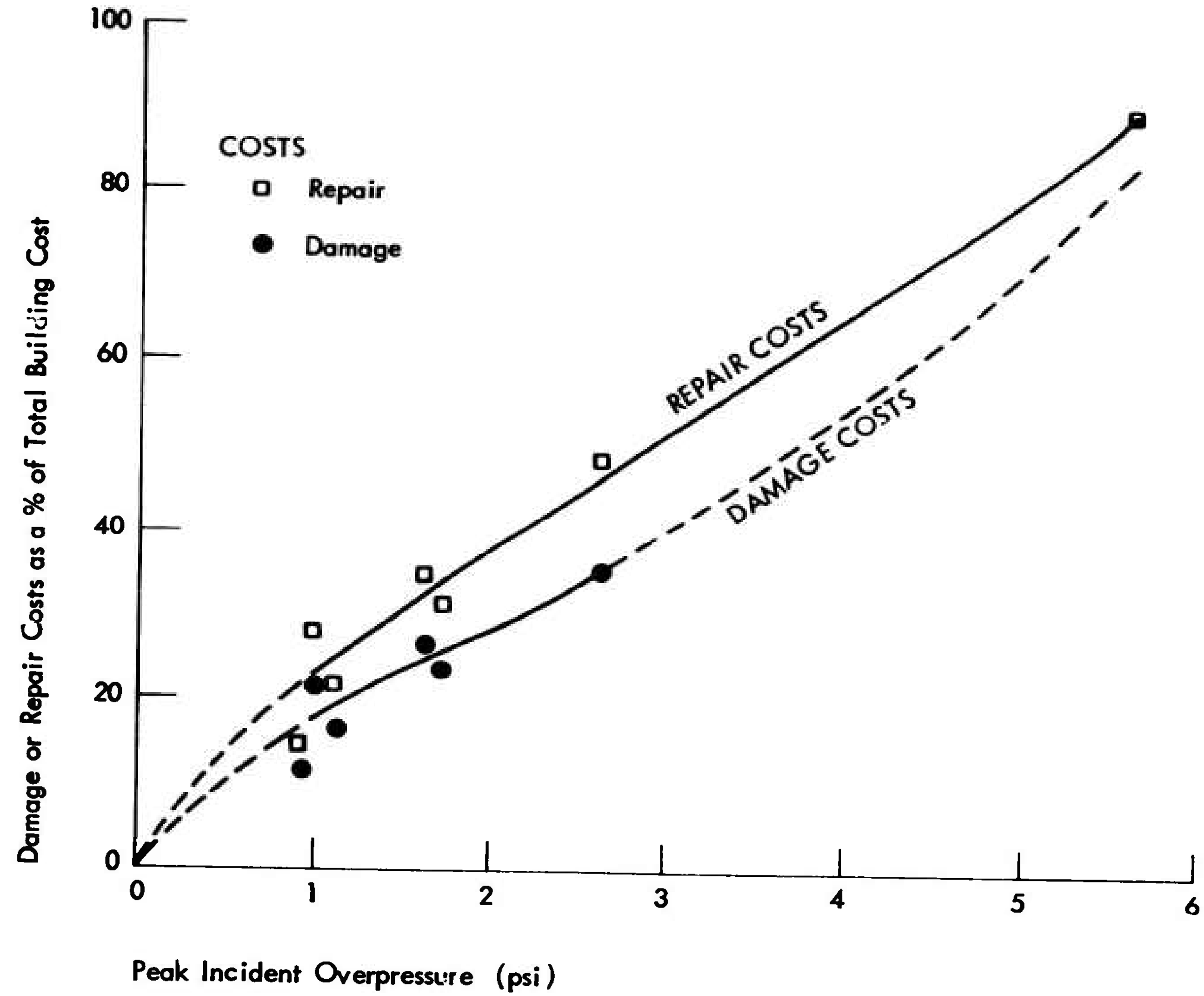


Fig. 6 DAMAGE AND REPAIR COSTS VS. PEAK INCIDENT OVERPRESSURE

Conclusions and Recommendations

The results of the tests reported on here, and the method proposed for quantifying damage (which when applied to the tests appear to indicate a strong correlation of damage or repair costs with overpressure) have significance for both the Armed Services Explosives Safety Board (ASESB) and the Office of Civil Defense (OCD), and also for evaluating effects of disasters other than those caused by explosion.

For ASESB, extension of these results and methods would:

- permit cost trade-off studies to be made to establish siting locations
- allow possible re-evaluation of Quantity-Distance Criteria
- aid in establishing legal basis for claims after an incident or accident

For OCD, extension of the results and methods proposed should:

- aid in post-attack recovery planning
- improve inputs to existing structure evaluation research
- aid in the development of casualty models

As indicated above the methods proposed can also be used for evaluating the extent of damage from non-explosive disasters (hurricanes, tornados, etc.) as well.

It is recommended that in the future:

- additional data on structural component and utilities damage be derived prior to conducting full-scale tests.
- future full-scale tests use structures employing more modern types of construction, and include tests on utilities (costs of which can be quantified as suggested in this paper).
- damage survey teams be established to document the effects of all types of disasters in order to increase the damage and repair cost data base.

REFERENCES

Ref. 1 Wilton, C. and J. Zaccor, Evaluation of Simultaneity Tests, URS 698-3, URS Research Company, Burlingame, California, January 1969.

Ref. 2 Dudash, M. J., Operation Prairie Flat Preliminary Report, Vol. 1, DASA 2228-1 and DASIAC SR 79, January 1969.

Ref. 3 Safety Tests of Nike-Hercules Sites (U), BRL Report No. 1085, November 1959 (C)

Ref. 4 Byrnes, Joseph B., Effects of an Atomic Explosion on Two-Story-And-Basement Wood-Frame Houses, WT-792, March-June 1953.

Ref. 5 Kaplan, K., and V. W. Davis, Effectiveness of Barricade: Review of Basic Information, URS 677-4R, DASA 2014, URS Corporation, Burlingame, California, June 1968.

FRAGMENT HAZARDS FROM MUNITION STACKS

D. I. Feinstein
and
H. H. Nagaoka
IIT Research Institute
Chicago, Illinois 60616

ABSTRACT

This paper describes an investigation of fragment hazards from multiple munitions in open stores. The objective of the study was to estimate fragment hazards as a function of type and quantity of munitions, configuration of the store and location of detonation origin.

A series of small and full scale tests, on a variety of stack configurations, were conducted in support of developing an analytic model for simulating an ammunition stack.

These experiments have tended to introduce complications in the development of an analytic stack model due to the observation of many unexpected results. The test results are being utilized in efforts to develop and validate an analytic procedure.

FRAGMENT HAZARDS FROM MUNITION STACKS

INTRODUCTION

This paper describes the work conducted under Phase III of the FRAGMENTATION HAZARD STUDY by IIT Research Institute (IITRI) under the technical direction of the Armed Services Explosives Safety Board (ASESB) under contract DAHC 04-69-C-0056 issued by the U.S. Army Research Office. A full understanding of the current research program described below is only achieved in the context of the total continuing program.

The overall objectives of this continuing effort are:

- To develop methodology for estimating risks of injury and damage from fragments
  - to a wide range of human, mechanical and structural targets,
  - at all ground ranges and orientations within the limit of vulnerability,
  - from simultaneous and repetitive detonation of various types and quantities of munitions,
  - in open stores and in protective enclosures,
  - expressing risk on a probability basis.
- To apply the methodology in determining levels of risk from fragments for a series of actual real-world sites.
- To conduct the analytical, empirical, and experimental studies required to fill gaps in current knowledge in support of the development of the methodology.

Phase I of the study was concerned with establishing quantitative damage criteria in terms of fragment mass, velocity and attack angle for various targets including standing personnel, vehicles, aircraft, buildings and open weapon stores. In Phase II an analytic model was developed to predict the density of fragments and the probability of damage to the targets considered in Phase I from explosion of individual munitions of various types.

These included gun shells and general-purpose bombs. Here, damage probability contours were obtained in polar coordinates for a horizontal orientation of the munition axis in each case.

In Phase III, the current research activity, the intent has been to extend the fragment hazard model, developed under Phase II for individual munitions, to the case of multiple munitions in open stores. The objectives of the study were:

- To extend the fragment hazard model to estimate quantity-distance relationships for fragment hazards as a function of type and quantity of munitions, configurations of the store and location of detonation origin.
- To conduct a full scale verification test to validate these quantity-distance relationships.

The analytic model for estimating fragment hazards includes the following salient features:

- Input which defines the initial spatial field of fragment masses, velocities and elevation angles.
- Application of trajectory analysis to determine terminal positions and terminal ballistic properties of fragments, and
- Utilization of vulnerability functions derived from available data for the determination of impact and damage probabilities.

In extending the analysis to include multiple munition sources (i.e., stacks) the only feature above which is affected is the input describing the initial spatial field.

This input, for the single muniton, was obtained from existing test results describing the fragmentation effectiveness of various munitions. No such similar information exists for stack configurations of these munitions. Therefore, the major research task in the Phase III study has been to establish a means of transforming the input data for a single munition into the corresponding input for a stack of this munition. This paper describes a series of small and full scale tests on stack configurations in support of developing an analytic stack model.

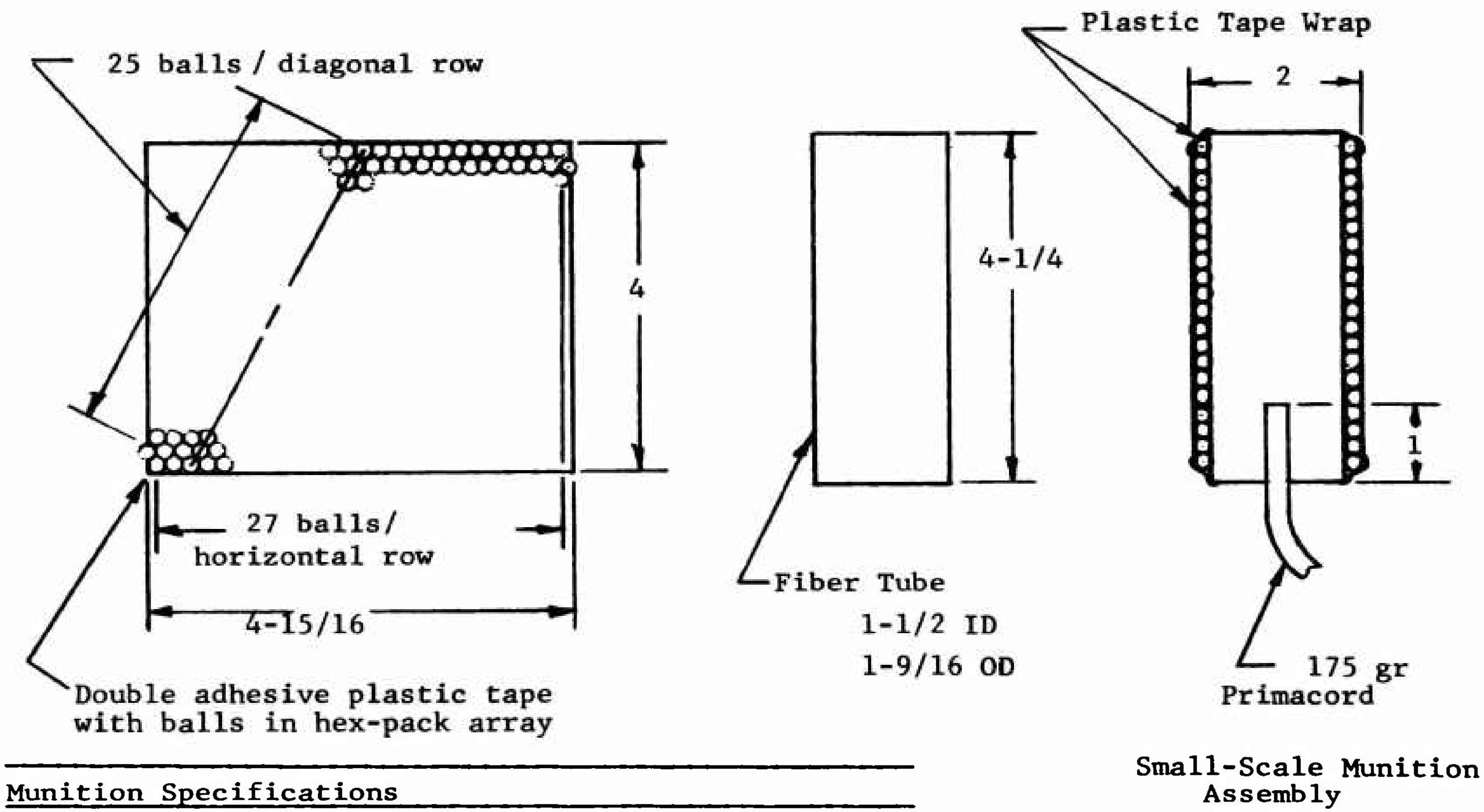
SMALL-SCALE EXPERIMENTS

During the current program, the fundamental information concerning the mechanism of fragment interaction was investigated for simultaneously detonated clustered small-scale munitions. The paucity of data concerning fragmentation for clustered munitions suggested that the basic explosive munition design be physically simple and predictable in behavior. Based upon this premise, the ball-type explosive munition configuration, illustrated in Fig. 1, was conceived with a simple cylindrical shape. An efficient fabrication technique was devised in which an exact number of ball bearings with minimum spacing could be assembled on the munition well with non-metallic components. An initial exploratory experiment, with the munition model loaded with C-4 explosive, verified that the ball fragments could be projected with uniform distribution and negligible loss due to shattered balls.

To obtain meaningful fragment interaction data for clustered munitions, a sixteen-sided closed arena was designed utilizing standard 4x8 ft. plywood panels that enclosed a diameter of about 20 ft. A schematic of the test arena is shown in Fig. 2. The arena design represented a compromise between the explosive model configuration (i.e., 2 inch diameter x 4 inch length) and a manageable arena structure which would provide full fragment interaction data. Heavy draft paper was stapled to each plywood panel to provide a portable data record of fragment interaction. In addition, three Celotex recovery boxes with 2x2 ft. surface were positioned 45 degrees apart to record fragment penetration data and to provide physical recovery of impacting fragment samples.

To further reduce the number of experimental variables, the munition clusters were detonated simultaneously. A total of twenty diagnostic experiments were conducted in which 92 small scale experimental models were detonated with 10 distinct cluster configurations. The resulting experimental data were processed in the following three categories:

- Qualitative photographic data from the impact witness panel paper.
- Counts of fragment impacts on the witness panel paper.
- A count of fragment perforations in the witness paper located between each inch of Celotex in the fragment recovery boxes.



Munition Specifications	
Weight of munition	405 gm
Number of balls	675 (3-16 in. diam, 52100 steel)
Weight of balls	299 gm
Weight of C-4 explosive	190 gm

Fig. 1 SMALL-SCALE MUNITION SPECIFICATIONS

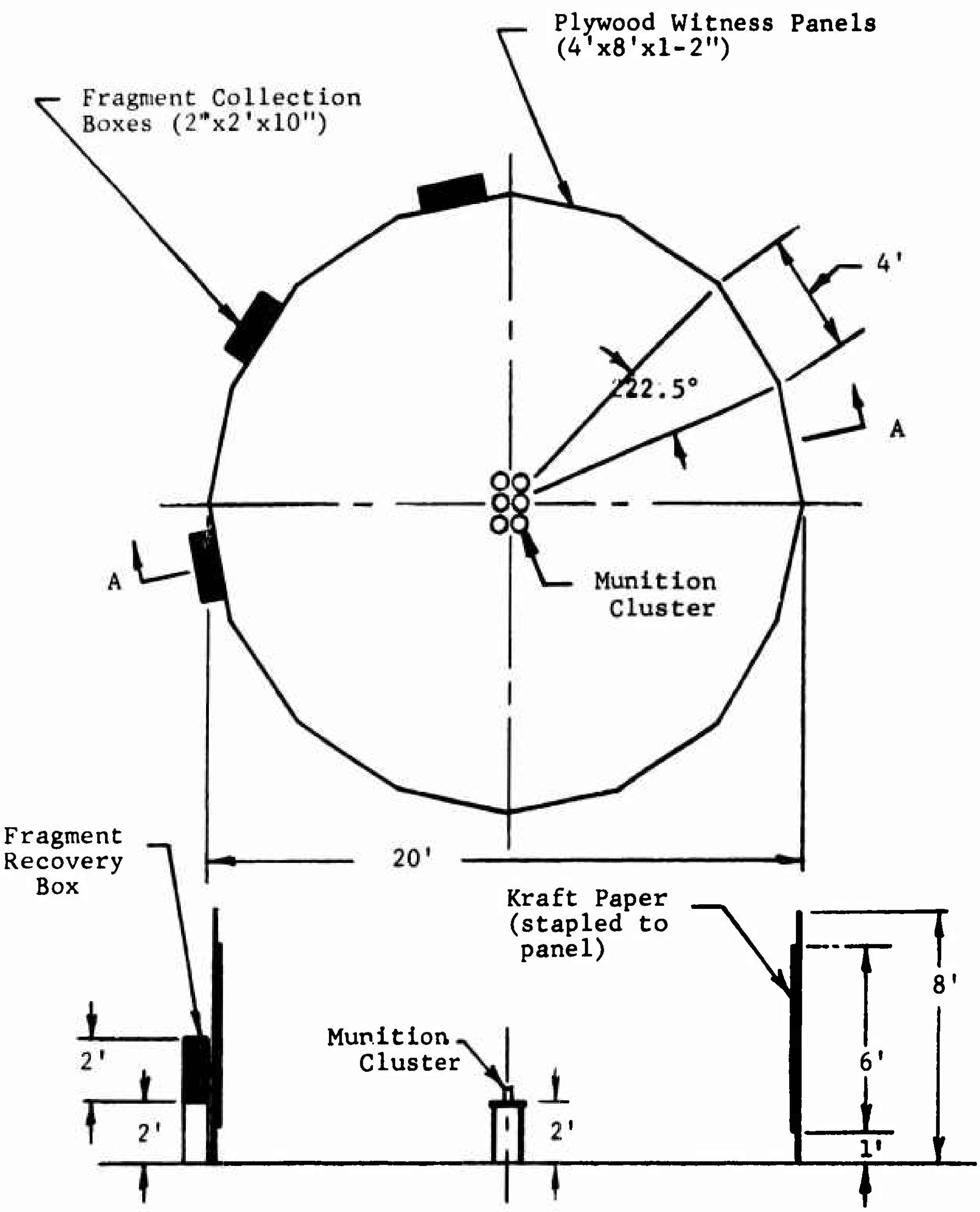


Fig. 2 SMALL-SCALE MUNITION ARENA FACILITY

The photographic data from the impacted witness panel paper were used to reconstruct the explosive model arena. These data provided conclusive evidence that simultaneous detonation of the model cluster was obtained as evidenced by the regular cyclic patterns between shattered and intact fragment zones.

The high energy fragment impacts (i.e., those fragments which projected an area greater than one-half that of a 3/16 in. sphere) were counted for each 11.25 degree sector on all witness panel sheets of the area. Table 1 indicates the results obtained for the 10 distinct cluster configurations. Figs. 3, 4 and 5 give graphic illustration of the relationship between the recovered balls and their corresponding position in the arena. It is readily apparent that in zones where interaction of fragments takes place that a concentration or enhancement effect takes place. In the zones where the ball bearings do not interact in flight, their behavior is equivalent to that expected from a single munition. Concentration also seems to be related to munition spacing as witnessed by fragment concentrations in an area sector angle of 22.5 degrees and 15 degrees for spaced and unspaced munitions respectively. Also spacing seems to affect the magnitude of concentration; that is, decreasing with separation.

The three Celotex recovery boxes, located 45 degrees apart, behind the plywood witness panels, provided information on fragment impact density and penetration energy for each munition of cluster. High energy fragments here were defined arbitrarily as those penetrating 5 inches of Celotex. The count of these fragment perforations showed good correlation with data obtained from corresponding arena witness panels. The Celotex penetration data also provided evidence that the fragment velocity is increased proportional to the number of munitions in the cluster. Table 2 summarizes the results of the Celotex recovery box data.

Finally, three experiments were conducted using naturally fragmenting steel cylinders in place of the cylinders with preformed fragments. The steel cylinders were designed to simulate the performance characteristics of the preformed fragment models. Results from these experiments verified that the fragment interaction phenomena may be correlated between the test models and configurations found in conventional ordnance items (i.e., with respect to side spray effects).

TABLE 1

SMALL-SCALE SUMMARY TEST RESULTS FOR DIFFERENT CLUSTER CONFIGURATIONS

CONFIGURATIONS	o	oo	o o	ooo	o o o o	o o o o	888	o o o o o o	o o o o o o o o o
BALLS FOUND	620	884	791	1168	934	1065	1591	1347	1433
BALLS AVAILABLE	675	1350	1350	2025	2025	2700	4050	4050	6075
PERCENT RECOVERY	91.8	65.5	58.6	57.7	46.1	42.9	39.3	33.3	23.6

TABLE 2

SMALL-SCALE CELOTEX RECOVERY BOX DATA

Config.	Angle	Number of balls through sheets 0	1	2	3	4	5	6
	90°	12	12	12	12	12	12	12
o	45°	12					12	
	0°	9					9	
	90°	69	48	31	27	25	24	18
o o	45°	16					12	
	0°	15					10	
	90°	46	28	26	23	23	23	20
oo	45°	12					10	
	0°	11					11	
	90°	118	54	42	34	28	22	15
ooo	45°	13					11	
	0°	14					11	
	90°		73	50	39	36	33	26
o o o	45°	12					9	
	0°	25					12	
	90°	124	61	38	33	26	26	14
o o o o	45°	15					14	
	0°	72	44	28	27	23	20	11
	90°	150	83	53	46	35	34	25
o o o o o o	45°	12					12	
	0°	48	33	25	22	18	17	11
	90°		145	81	41	31	26	22
888	45°	13					12	
	0°		111	58	35	30	24	17
	90°		117	69	46	39	35	28
o o o o o o o o o	45°		15				12	
	0°		157	88	58	53	45	35

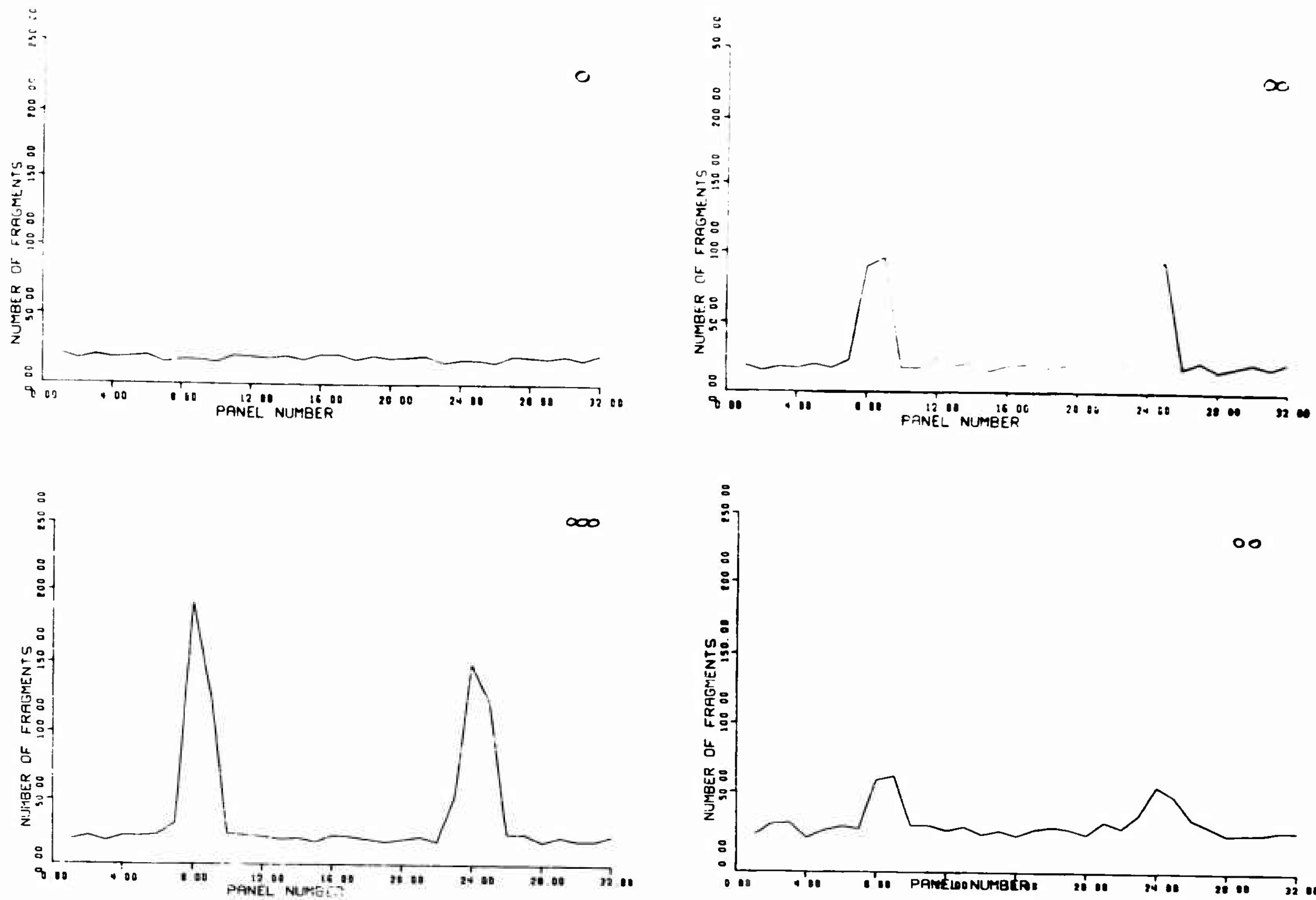


Fig. 3 FRAGMENT COUNT AT PANELS

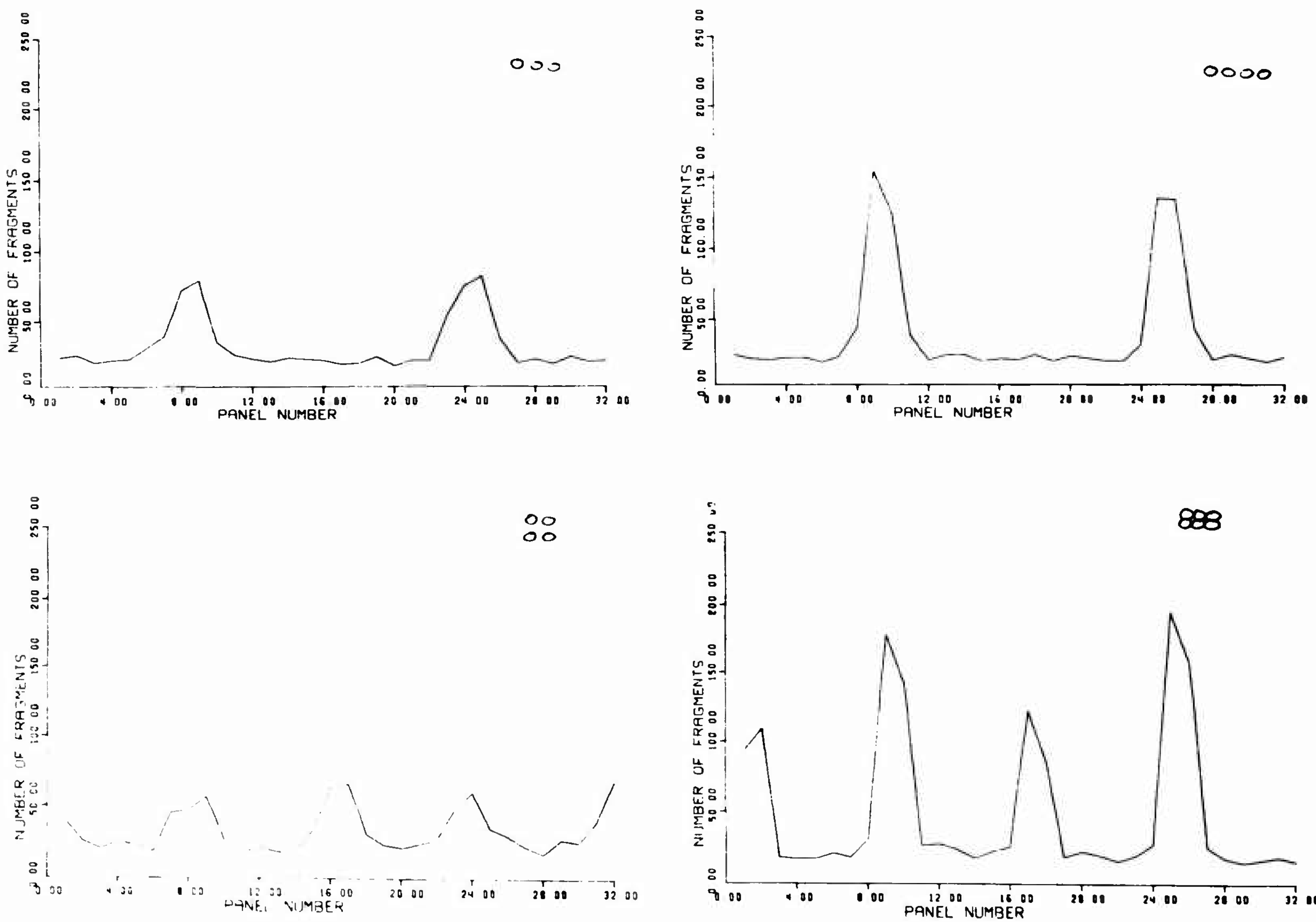


Fig. 4 FRAGMENT COUNT AT PANELS

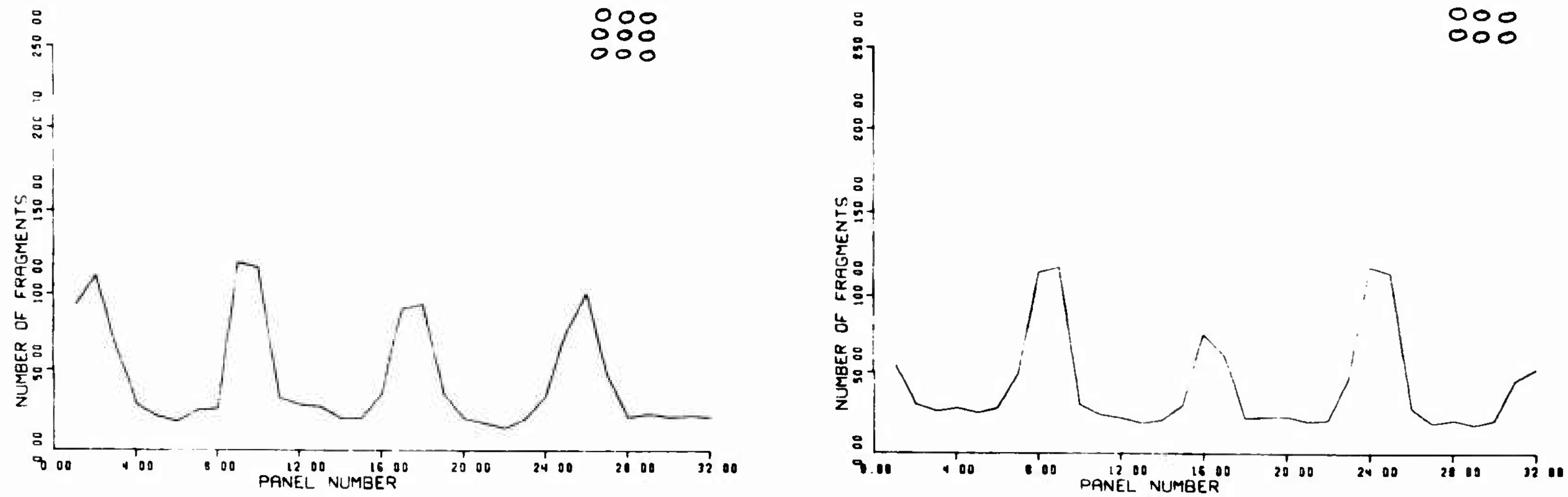


Fig. 5 FRAGMENT COUNT AT PANELS

FULL SCALE M11-7 BOMB TEST

In order to validate the extended fragment hazard model a full-scale experiment, utilizing stacked 750 lb M117A1E1 bombs, was conducted by the Naval Weapons Center (NWC) at China Lake, California. The experiment was conducted as two test series consisting of a 6-bomb cluster and a 15-bomb cluster. In each experiment all units were primed and detonated simultaneously. The 6-bomb cluster was configured as three-high and two-wide. This cluster had all bombs yielding some measure of unobstructed side-spray fragments. The second configuration consisted of 15 bombs stacked three-high and five-wide. This cluster provides six bombs entirely masked by the peripheral nine bombs. These stack configurations are shown in Figs. 6 and 7 respectively. Fig. 8 illustrates the test area at China Lake.

Using a vehicle-mounted electromagnet, NWC collected case material fragments after each experiment in eight angular sectors, each subtending an angle of 8°-36'. Each sector was subdivided into eight cells between the 500-ft and 2000-ft radial distances from the location of the bomb cluster. Fragments in each of the 64 cells throughout the test area were passed through a series of 12 sieves. The number of fragments retained in each sieve was counted and the total weight was also recorded. The average fragment mass was readily obtained.

Having the average fragment mass and the number of fragments in each cell of the recovery area provides for sufficient data to validate the extended fragmentation hazard model. Table 3 gives the total weight of fragments in each sector for both the 6 and 15 bomb tests.

TABLE 3

TOTAL WT. TABLE - CHINA LAKE

Sector	Weight of Fragments, lb. 3x2	5x3
A	6.58	15.95
B	23.77	42.17
C	15.67	49.19
D	12.26	119.94

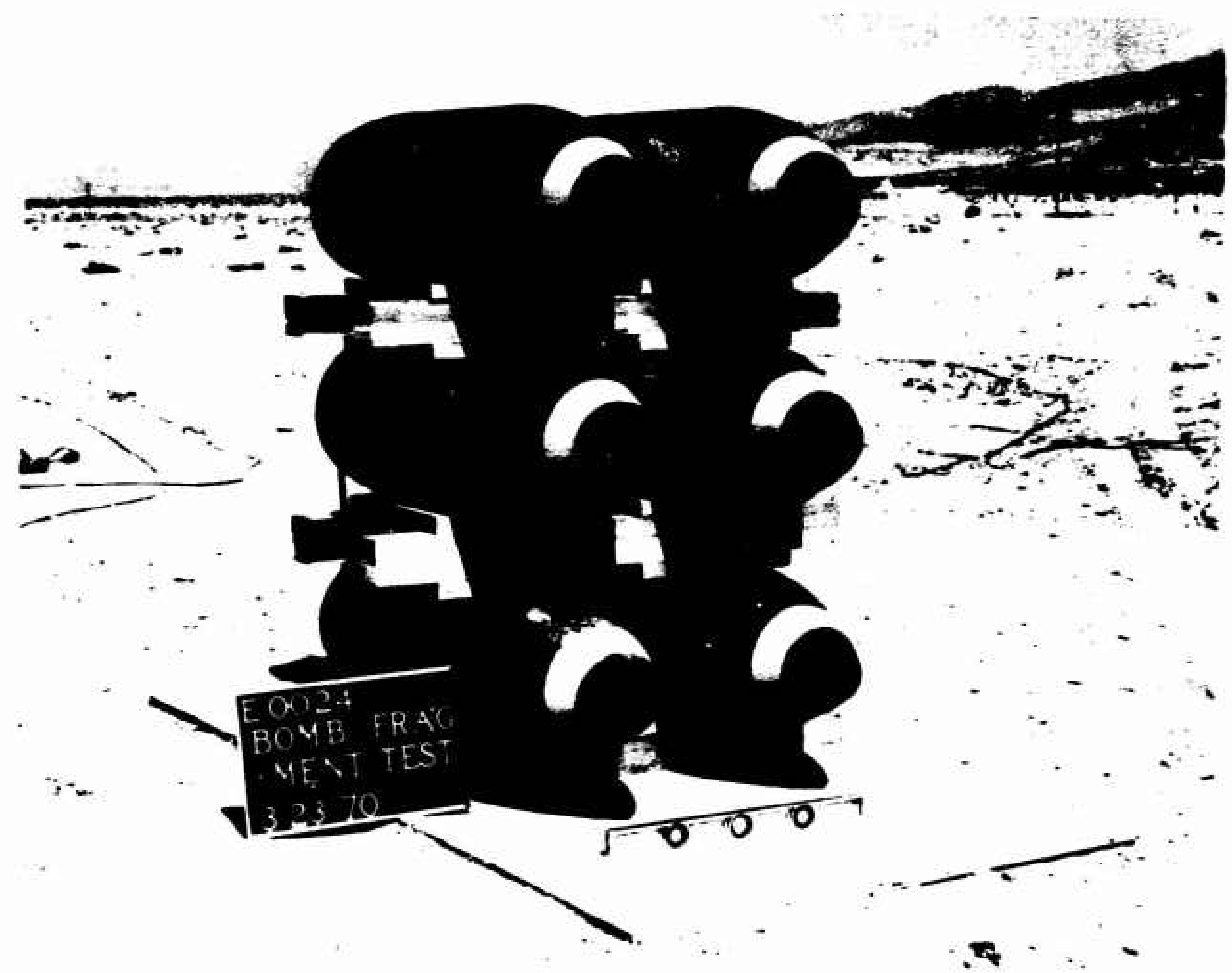


Fig. 6 TEST CONFIGURATION (2 x 3) AT CHINA LAKE

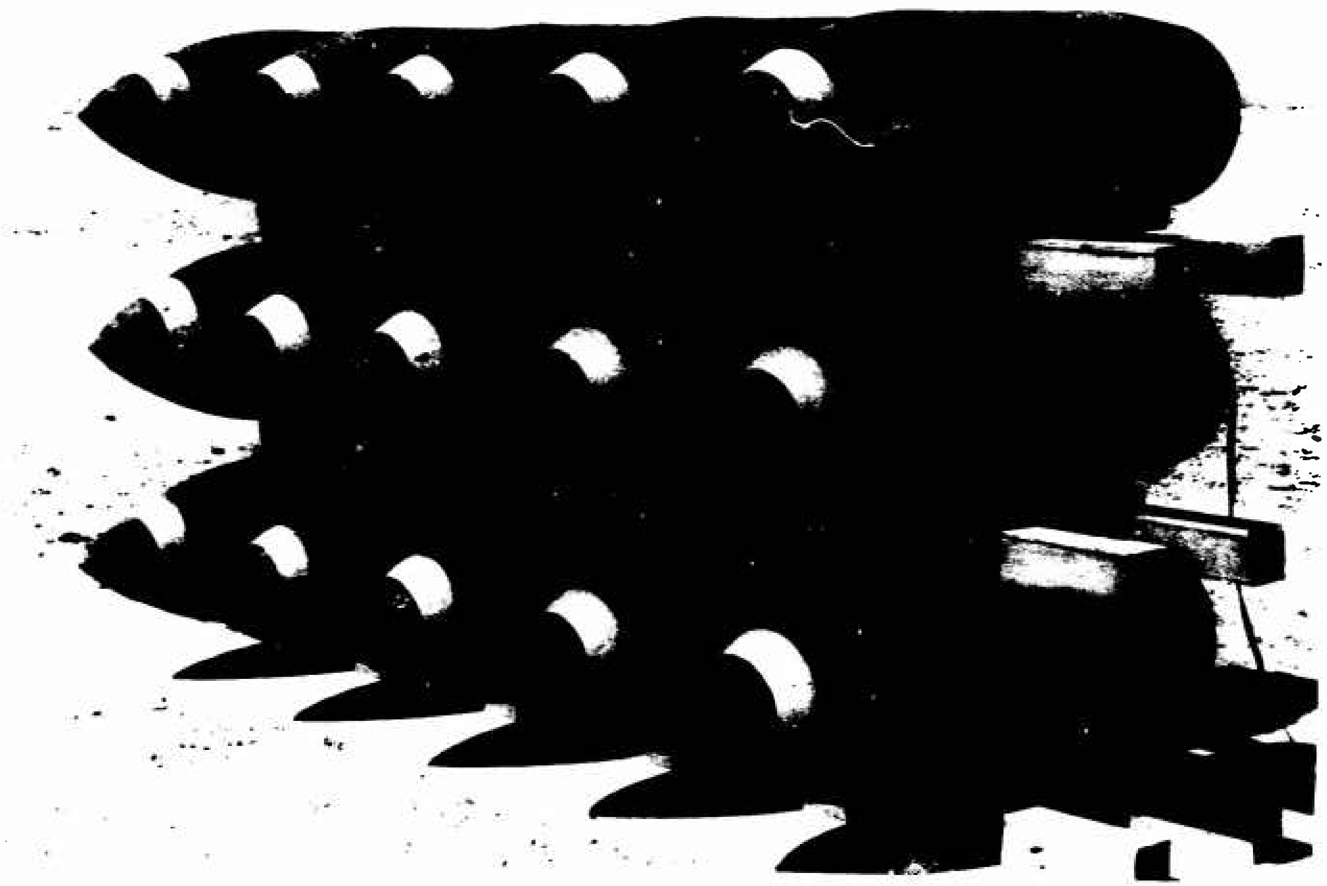
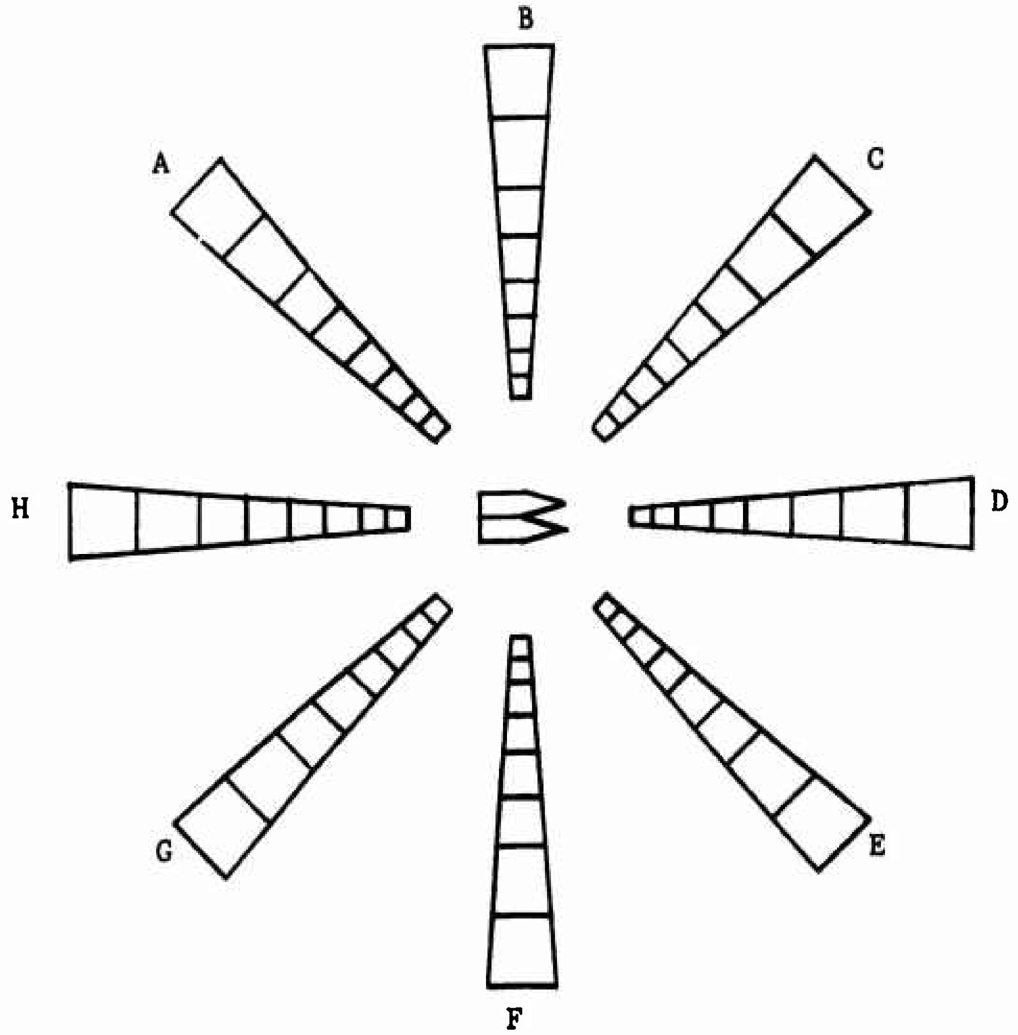


Fig. 7 TEST CONFIGURATION (3 x 5) AT CHINA LAKE



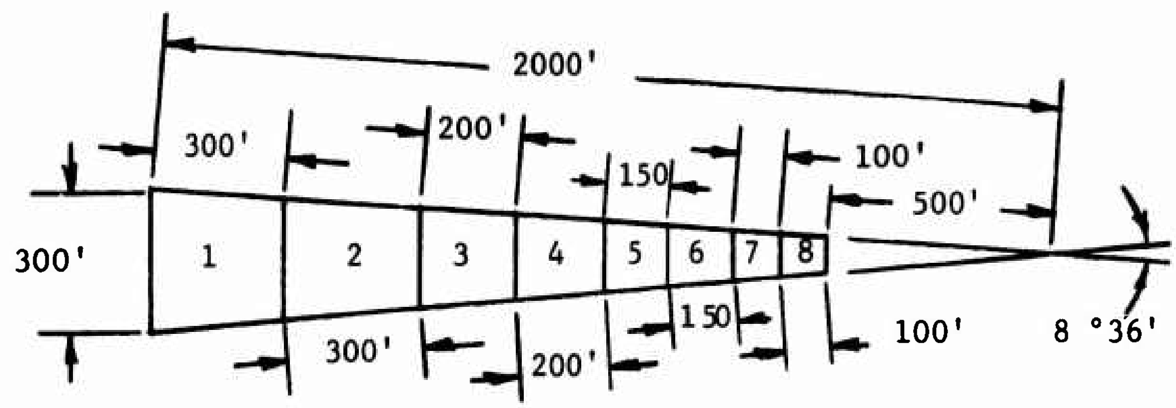


Fig. 8 NWC FRAGMENT COLLECTION CELL SPECIFICATION

These data indicate that the basic experimental design structure was functional in providing hazard information. More specifically, it was evident that fragment hazards from the accidental detonation of munition stacks is quite sensitive to the physical configuration of the munition. That is, the fragment hazard from stacked artillery munitions may differ significantly from stacked aerial bombs because of the difference in the metal case configuration and the explosive charge-to-metal mass ratio.

FULL SCALE 155mm SHELL TESTS

To ascertain the degree to which physical configuration of munitions plays a role in the fragment hazard study, IITRI participated in two experiments conducted at Yuma Proving Ground.

The first experiment consisted of 1000 units of 15mm shells stacked 10-high and 100-wide in a parallel array. The stack was detonated by a single 15mm shell with the remainder of the stack initiated by sympathetic detonation.

The second experiment consisted of three rows of 155mm shells with 100 units each stacked 10-high and 100-wide. The first two rows were aligned base-to-base, while the second and third rows were oriented nose-to-nose. Each row was spaced 50 inches apart with the middle row designated the donor stack with primed munition.

The fragment collection cell specifications are illustrated in Fig. 9. Three sectors are shown spaced 90 degrees apart. Although the original intent was to have all three sectors subtend an angle of 8°-36', the magnitude of resulting fragments made it necessary to reduce the collection areas in the nose and base sectors as shown. All fragments within each sector were collected from 500 ft to 2000 ft distances measured along the radial borders of the sector. Each sector was divided into eight cells. As in the bomb test at China Lake, a truck mounted electromagnet was utilized to collect the fragments in each of the 24 collection zones.

It should be noted here that the primary objective of the Yuma program included the obtaining of blast measurements at strategic locations, photographic data on explosion propagation and fragment velocity, and fragment recovery in Celotex boses. The IITRI fragment recovery program represented a secondary objective of the test which in no way interfered with the test's primary objective.

Table 4 represents the results of the first test at Yuma. As shown in Fig. 9 and previously discussed, the collection cells were not similar in size. It was therefore necessary to normalize the results obtained.

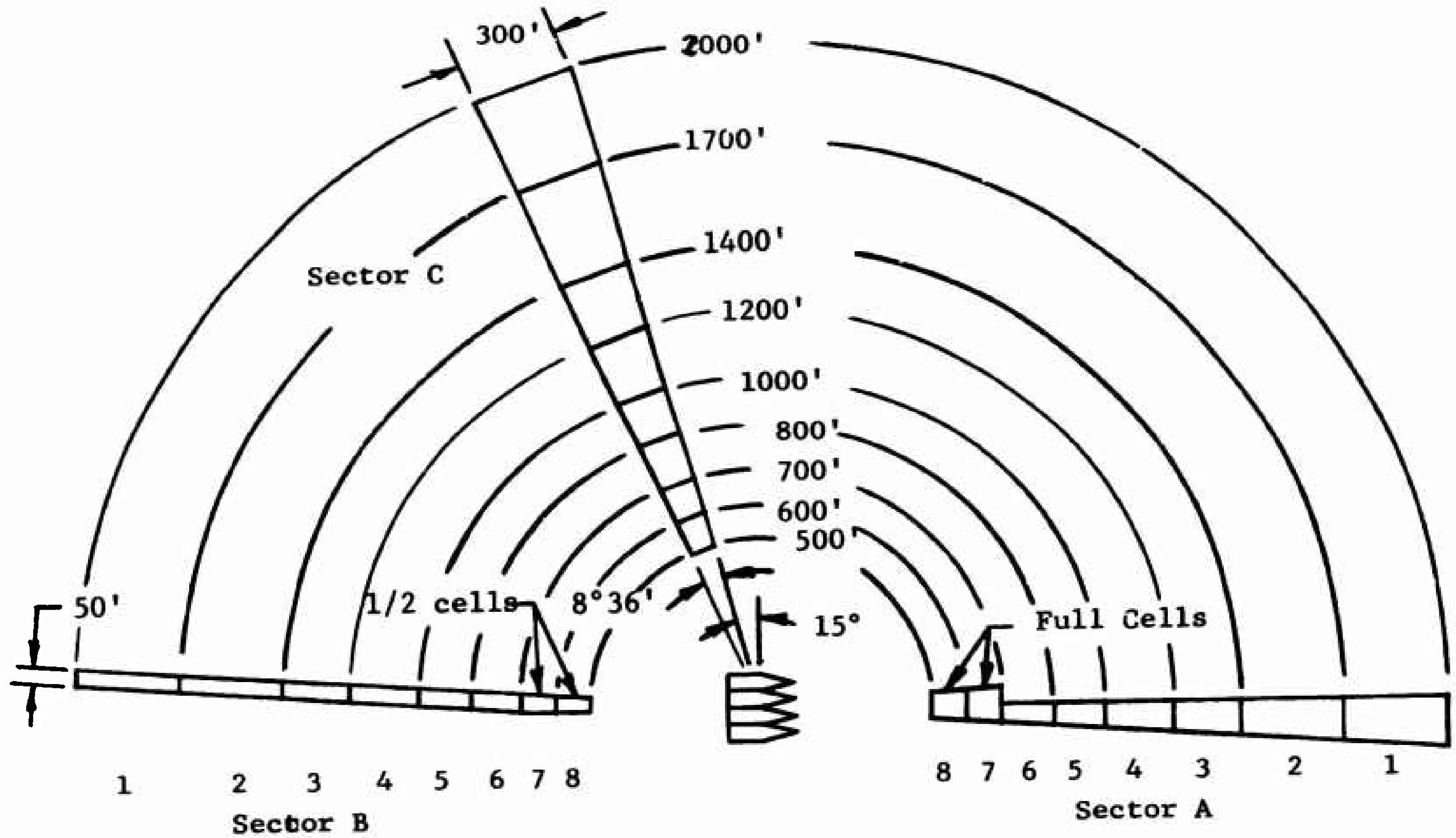


Fig. 9 YUMA FRAGMENT COLLECTION CELL SPECIFICATIONS

Table 4

YUMA FRAGMENT WEIGHT DATA FROM TEST 1

Cell No.	A Nose Sector	B Base Sector	C Side Sector
1	88.8	165.6	12.0
2	92.2	333.9	30.2
3	281.2	259.3	--
4	237.3	359.0	38.2
5	278.9	261.4	44.3
6	428.1	280.4	44.4
7	268.4	272.5	43.3
8	229.5	186.1	45.1
TOTAL	1909.4	2118.8	262.5
Total Fragment Weight = 4290.7 lbs			

Table 5 shows the results of normalizing the total fragment weights in the nose and side sectors to the base sector due to an area estimate. The results obtained from the first experiment at Yuma were totally unexpected. Instead of obtaining a fragment pattern which is somewhat consistent with results obtained for a single munition, the shells in the stack seemed to fracture like a banana peeling. That is, the nose plug was thrown into the nose sector as expected; however, the majority of fragments in the base zone were large chunks of casing material (i.e., long 9-18 inch and heavy in excess of 5 lb weight). Furthermore, the large fragments in the base zone were extremely dense and this density did not seem to be falling off considerably at the maximum collection cell 2000 ft out. Large fragments were found at distances in excess of 3200 ft. The relatively small amount of material found in the side sector is consistent with the above results in that only the shells on the perimeter of the stack probably contributed to this sector.

In the second test at Yuma, the fragment pattern was significantly different than the one obtained from the previous tests. Here, only the center stack detonated. The shells from the two adjoining stacks were distributed over a large area; as far as 4500 feet from ground zero. The detonated shells fragmented in the same manner as before. However, a large number of fragments that would have been projected into the nose and base sector were effectively blocked by the adjoining stacks and remained at ground zero. In these sectors the fragment density appeared to be less than a third of that previously observed. The density dropped off quite rapidly in cells 2 and 1. The side spray sector appeared to have the same pattern as before. The ends of the undetonated shells that were facing towards the center stack (i.e., bases of the base-to-base and the noses of the nose-to-nose) were considerably deformed from the impacts of the fragments from the detonated shells.

EXTENDED FRAGMENT FIELD PREDICTION MODEL

The series of experiments that were conducted has tended to complicate the task of developing an analytic stack model which can predict the initial fragment field of a stack of munitions from the corresponding data for a single munition. These complications are due to the following test observations:

> The small-scale test indicates zones of material and velocity enhancement which are dependent on stack configuration and spacing.

- Since the small-scale tests were conducted with cylinders, this effect is only demonstrated for side spray. However, the bomb tests at China Lake also show enhancement zones in the base and nose sectors.

- The full scale bomb tests at China Lake have shown that the fragment input data obtained for a single munition lacks adequate resolution for the heavier fragment weights.

- The Yuma tests indicate that the fragment size may vary as a function of individual munition case design and the contact area of shells within a stack.

Since the Yuma effect has been a rather recent and entirely unexpected phenomena and one which is presently not entirely understood, the present discussion will be limited to the techniques now being employed to replicate the bomb results, obtained at China Lake, with the fragment hazard model.

In the Fragmentation Hazard Study, Phases I and II, test results for single munitions were utilized. These results defined the initial spatial field of fragment masses, velocities, and elevation angles. The full-scale small-stack bomb tests at the NWC showed the importance of the heavy fragments. However, in the model these heavy fragments were grouped into only the top two categories.

IITRI is presently obtaining raw data on single munition bomb fragment tests from Eglin Air Force Base which will allow us to redistribute the mass categories in a more representative table as input to the model.

The input table will be further refined to incorporate material enhancement within the interval of polar angle representative of side-spray. Since this angle is not specifically known, the problem will be treated parametrically. That is, material enhancement rules, as observed from the small-scale tests, will be appropriately applied to the redistributed input table.

Table 5

NORMALIZED YUMA RESULTS FROM TEST 1

Area Estimate		Recovered Fragment Weight	Normalized Fragment Weight	Relative Fragment Weight
Base	1	2118.8	5932.6	22.6
Nose	1.4	1909.4	3818.8	14.4
Side	2.8	262.5	262.5	1

(1) Normalized fragment weight based upon estimated equivalent collection areas.

(2) Relative fragment weight as compared with weight collected in Side Sector.

CONCLUSIONS

Based on the test results obtained in this study, one may conclude the following:

1) Zones of velocity enhancement and material enhancement tend to develop within areas where one munition shades another in a stack. This phenomena of enhancement is shown to behave in a predictable manner for the small-scale tests corresponding to side effects.

2) This enhancement is confirmed and extended to nose and base effects as well as side effects.

3) Current input data for single munitions lacks sufficient resolution for heavier fragments to be useful as input to the fragment hazard study.

4) The Yuma tests indicate that the fragment size may vary as a function of individual munition case design and the contact area of munitions within a stack.

5) The Yuma tests also show that stacking techniques may be employed to minimize the fragment hazard effect.

BLANK PAGE

REVIEW OF FIRE HAZARD DISTANCES

A. N. Takata
Senior Research Engineer
IIT Research Institute
Chicago, Illinois 60616

ABSTRACT

This paper describes the results of an analytical study of the effect of thermal radiation from fires in magazines and liquid-fuel storage areas on various targets as well as the separation distances required to prevent serious damage. The study included buildings with and without windows, trains, automobiles, aboveground magazines, aircraft and human beings. It was concluded that the current separation distance requirements for solid-fuels are excessive and that the scaling of the distances to the one third power of the total weight of fuel is incorrect. Furthermore, it was concluded that the separation distances for liquid-fuels should be based on the area over which the fuel may flow rather than on its total weight. Means for including the effect of fuel composition on the separation distances are also included.

REVIEW OF FIRE HAZARD DISTANCES

I. INTRODUCTION

Fires in magazines or in liquid-fuel storage areas can seriously damage targets either as a direct result of the radiant heating of sensitive target components or as a result of fires started within targets. This study is concerned with the quantity-distance requirements associated with fire. In this paper, we will discuss the principal factors that affect the radiation emitted by two types of fires, namely,

- fires involving pools of liquid fuels, and
- solid-fuel fires,

and the radiant intensities necessary to damage or injure various types of targets, namely,

- aircraft
- magazines,
- buildings,
- vehicles,
- trains, and
- human beings.

II. RADIATION PRODUCED BY FIRE

Here we are concerned with accidental fires in which the principal mechanism of damage is thermal radiation and not by blast, fragmentation, or the ejection of burning debris. The thermal damage varies from the ignition of targets such as buildings to the buckling of

aircraft skins and depends on the radiant intensity and exposure time. In most accidental fires, the fire duration is long compared to the times for thermal damage so that the damage is primarily dependent on the intensity of the radiation. Thus, fires that generate intense radiation for short periods of time are more hazardous to targets than fires which emit the same quantity of heat over longer periods of time. Aside from distance, there are four major factors that affect the radiant intensity. These are listed below in the order in which they affect the radiant intensity.

1. Rate of heat generation by fire

2. Fraction of heat radiated by flame

3. Deflection of convection column by wind

4. Transmissivity of atmosphere associated with emitted radiation.

First we will discuss the last three items and then discuss the rate of heat generation. The fraction of heat radiated by flames varies with the fuel and usually ranges from about 17 to 42 percent of the total heat depending on the composition of the fuel.[1*] On the other hand, wind can cause appreciable changes in the radiant field by deflecting the flames either towards or away from targets. In the downwind direction, the wind may increase the radiant intensities by as much as 65 percent above those produced under conditions of no wind while the radiant intensities in the upwind direction are decreased by as much as 80 percent.

The radiation emitted by fires incurs substantial attenuation enroute to a target and varies with the percent of water vapor and carbon dioxide in the air and the spectral distribution of radiation. At 300 ft, the reductions of the radiant intensities due to attenuation range from about 22 to 41 percent while at 900 ft the reductions of the radiant intensities range from about 33 to 46 percent.[2] Of all the factors, the rate of heat generation is singly the most important and is a function of the rate of consumption of the fuel and the amount of heat generated per unit weight of fuel.

---

*Numbers in superscript refer to "References" listed at the end of the text.

2.1 Rate of Heat Generation by Liquid Fuel Burning in Pools

For liquid-fuel fires, the rate of fuel consumption is equivalent to the product of the total surface area of the burning pool and the rate of vaporization of fuel per unit area of surface. The rate of vaporization varies with the fuel composition while the surface area of the liquid varies with the enclosure within which the liquid is confined. The total quantity of fuel is important only insofar as it affects the surface area of the fuel exposed to fire. Unfortunately, the distance requirements of the present quantity-distance tables are expressed in terms of the total quantity of fuel rather than on the availability of the fuel to participate in a fire.

For pool fires, the rate of heat generation q_o can be approximated by the following equation:

$$q_o = c \cdot A \cdot \rho \cdot Q^2 / Q_v \qquad (1)$$

where

c = Constant of proportionality

A = Surface area of pool

ρ = Density of fuel

Q = Heat of combustion of fuel

Q_v = Heat necessary to vaporize fuel.

This equation is based on experiments which indicate that the rate of consumption of fuel is proportional to the ratio of the heat of combustion divided by the heat necessary to vaporize the fuel.[1]

2.2 Rate of Heat Generation by Fires Involving Solid Fuels

The rate of heat generation from fires involving solid fuels such as propellants, incendiary materials and certain explosive materials is difficult to ascertain because the times to burn individual fuel elements are short compared to the times for fire spread. This is a result of the very appreciable thermal protection afforded fuel elements by packaging materials and cases.[3] The problem of predicting the rate of heat generation is further complicated by substantial variations in this protection. One means of assuring that targets are not seriously

damaged is to consider the most severe fire in which all fuel elements ignite simultaneously. In the context of safety, such an approach will require one to locate potential sources of fire at excessive distances from targets. This is particularly true for the case of large fuel arrays since the times for fire spread through such arrays are apt to be substantial. The principal argument for assuming that all fuel elements ignite simultaneously is that it will assure* targets are not seriously damaged regardless of how the fire starts or spreads. A certain level of risk is implied otherwise.

For the case of simultaneous ignition, the rate of heat generation q may be expressed as

$$q = A_i \cdot V_i \cdot Q_i \qquad (2)$$

where

A_i = Total surface area of i-th fuel element

V_i = Velocity of burning of i-th fuel

Q_i = Heat generated by burning of unit mass of i-th fuel.

III. CRITICAL RADIATION EXPOSURES ASSOCIATED WITH VARIOUS TARGETS

Four curves showing the minimum incident radiant intensities necessary to ignite or seriously damage various types of targets are shown in Fig. 1. The interior fuel for buildings is considered as black cotton cloth with a backing material which is located just behind a single window pane while the exterior fuel is considered as wood sidings that are painted black. The curve associated with interior building fuels is also considered appropriate for automotive vehicles and trains. For open stacks of ammunition or similar materials, we have considered IMR propellant with a black coating directly exposed to the radiation. For the case of human beings, the critical irradiance is associated with second degree burns of the bare skin of individuals whose skin has an absorptivity of 0.6 and who constantly turn to ward off the painful effects of the heating. In each of the above

*If distance is required accordingly.

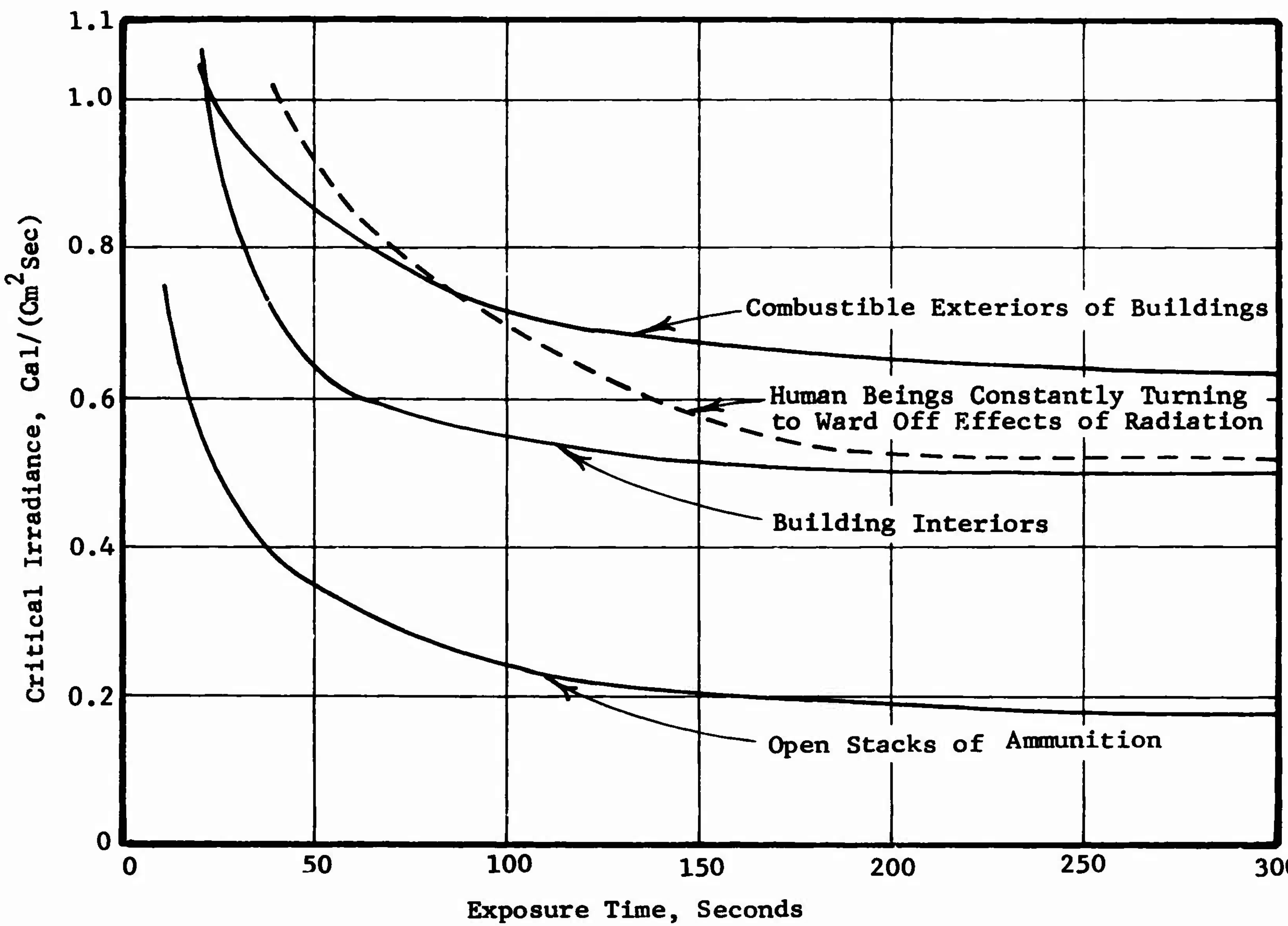


Fig. 1 MINIMUM RADIANT EXPOSURES NECESSARY TO IGNITE OR DAMAGE VARIOUS TARGETS

cases, the affected surfaces are treated normal to the direction of the fire. Except for human beings that are immobilized, all other situations and fuels will require greater irradiation to cause serious damage.

IV. DISTANCE REQUIREMENTS

Throughout this paper, we have assumed a condition of no risk and, hence, have considered the most severe fires and the most vulnerable targets. Tables 1 through 5 document the distance that various types of targets must be from the nearest edge of the area of fire. Tables 1 and 2 are for solid-fuel fires and present the distances in terms of the duration of the fire and the weight of the fuel. Tables 3, 4 and 5 are for fires involving liquid-fuel and present the distances in terms of the surface area of the fuel and $\rho \cdot Q^2/Q_v$. This group of parameters is a measure of the rate of heat generation by the fuel, where ρ and Q are the density and heat of combustion of the fuel, respectively, and Q_v is the heat necessary to vaporize the fuel.

Figures 2 and 3 summarize the more important aspects of the fire problem. These are that the threat of fire is most appropriately a function of the rate of heat generation by the fire. For fires involving solid fuels, the rate of heat generation can be characterized by the total weight of fuel and the duration of the fire as shown in Fig. 2. The importance of each of the two parameters is self-evident. For fires involving liquid fuels, the rate of heat generation may be characterized by the surface area of the pool and the properties of the fuel as shown in Fig. 3. Both parameters have an appreciable effect on the distances. The quantity of liquid fuel is important only insofar as it affects the areas over which the fuel is able to flow.

Unfortunately, existing quantity-distance Tables[4] are developed solely on the basis of total weight of fuel and make no provision for fire duration for the case of solid fuels or for the surface area or fuel composition for the case of liquid fuels. Furthermore, there is no sound basis for scaling the distances to the one-third power of the total weight.

TABLE 1

DISTANCE REQUIREMENTS FOR SOLID-FUEL FIRES BURNING FOR 1 MINUTE

Fuel Weight (lbs)	Buildings with Windows, Rail-road and High-way Distances (ft)	Buildings without Windows with Combustible Exteriors (ft)	Aboveground Magazine (ft)	Aircraft (ft)	Human Beings (ft)
100	7	7	8	12	7
500	16	15	18	26	15
1,000	23	22	25	37	22
5,000	50	48	54	79	47
10,000	69	66	74	109	65
20,000	95	91	102	152	90
40,000	132	127	143	210	125
60,000	160	154	173	255	152
80,000	183	176	197	292	174
100,000	203	195	219	324	193
200,000	282	271	304	449	268
400,000	392	376	422	620	371

TABLE 2

DISTANCE REQUIREMENTS FOR SOLID-FUEL FIRES BURNING FOR 3 MINUTES

Fuel Weight (lbs)	Buildings with Windows, Railroad and Highway Distances (ft)	Buildings without Windows with Combustible Exteriors (ft)	Aboveground Magazine (ft)	Aircraft (ft)	Human Beings (ft)
100	5	5	6	8	5
500	10	10	13	19	11
1,000	15	14	18	26	16
5,000	32	31	40	57	35
10,000	45	43	56	79	48
20,000	62	61	78	109	67
40,000	86	84	107	152	93
60,000	103	101	130	184	112
80,000	119	116	149	210	129
100,000	132	129	166	234	143
200,000	183	179	230	324	198
400,000	254	248	319	449	275

TABLE 3

DISTANCE REQUIREMENTS FOR LIQUID-PROPELLANT POOL FIRES, $\rho \cdot Q^2/Q_v = 1.10^7$ Btu/ft^3

Area of Propellant Pool ft^2	Buildings with Windows, Railroad and Highway Distances (ft)	Buildings without Windows with Combustible Exteriors (ft)	Aboveground Magazine (ft)	Aircraft (ft)	Human Beings (ft)
100	8	8	11	16	9
500	18	18	24	34	20
1,000	26	26	34	48	28
2,000	36	36	48	67	39
4,000	50	50	67	94	55
6,000	61	61	81	114	67
8,000	70	70	93	131	77
10,000	78	79	104	146	86
20,000	110	110	145	204	120
40,000	153	154	203	285	167
60,000	186	187	247	346	204
80,000	214	215	284	397	234
100,000	239	239	316	442	260

TABLE 4

DISTANCE REQUIREMENTS FOR LIQUID-PROPELLANT POOL FIRES, $\rho \cdot Q^2/Q_v = 3 \cdot 10^7$ Btu/ft^3

Area of Propellant Pool ft^2	Buildings with Windows, Railroad and Highway Distances (ft)	Buildings without Windows with Combustible Exteriors (ft)	Aboveground Magazine (ft)	Aircraft (ft)	Human Beings (ft)
100	14	14	19	27	16
500	31	31	41	58	34
1,000	44	44	58	81	48
2,000	61	61	81	114	67
4,000	86	86	114	159	93
6,000	104	104	138	194	114
8,000	120	120	159	222	131
10,000	133	134	177	248	146
20,000	186	187	247	346	204
40,000	260	261	345	483	284
60,000	317	317	419	586	346
80,000	364	364	481	673	397
100,000	405	406	536	749	442

TABLE 5

DISTANCE REQUIREMENTS FOR LIQUID-PROPELLANT POOL FIRES, $\rho \cdot Q^2/Q_v = 6 \cdot 10^7$ Btu/ft^3

Area of Propellant Pool ft^2	Buildings with Windows, Railroad and Highway Distances (ft)	Buildings without Windows with Combustible Exteriors (ft)	Aboveground Magazine (ft)	Aircraft (ft)	Human Beings (ft)
100	20	20	26	37	22
500	44	44	58	81	48
1,000	61	61	81	114	67
2,000	86	86	114	159	93
4,000	120	120	159	222	131
6,000	146	146	193	271	159
8,000	167	168	222	311	183
10,000	186	187	247	346	204
20,000	260	261	345	483	284
40,000	364	364	481	673	397
60,000	442	443	585	817	482
80,000	507	508	671	938	554
100,000	565	566	747	1043	616

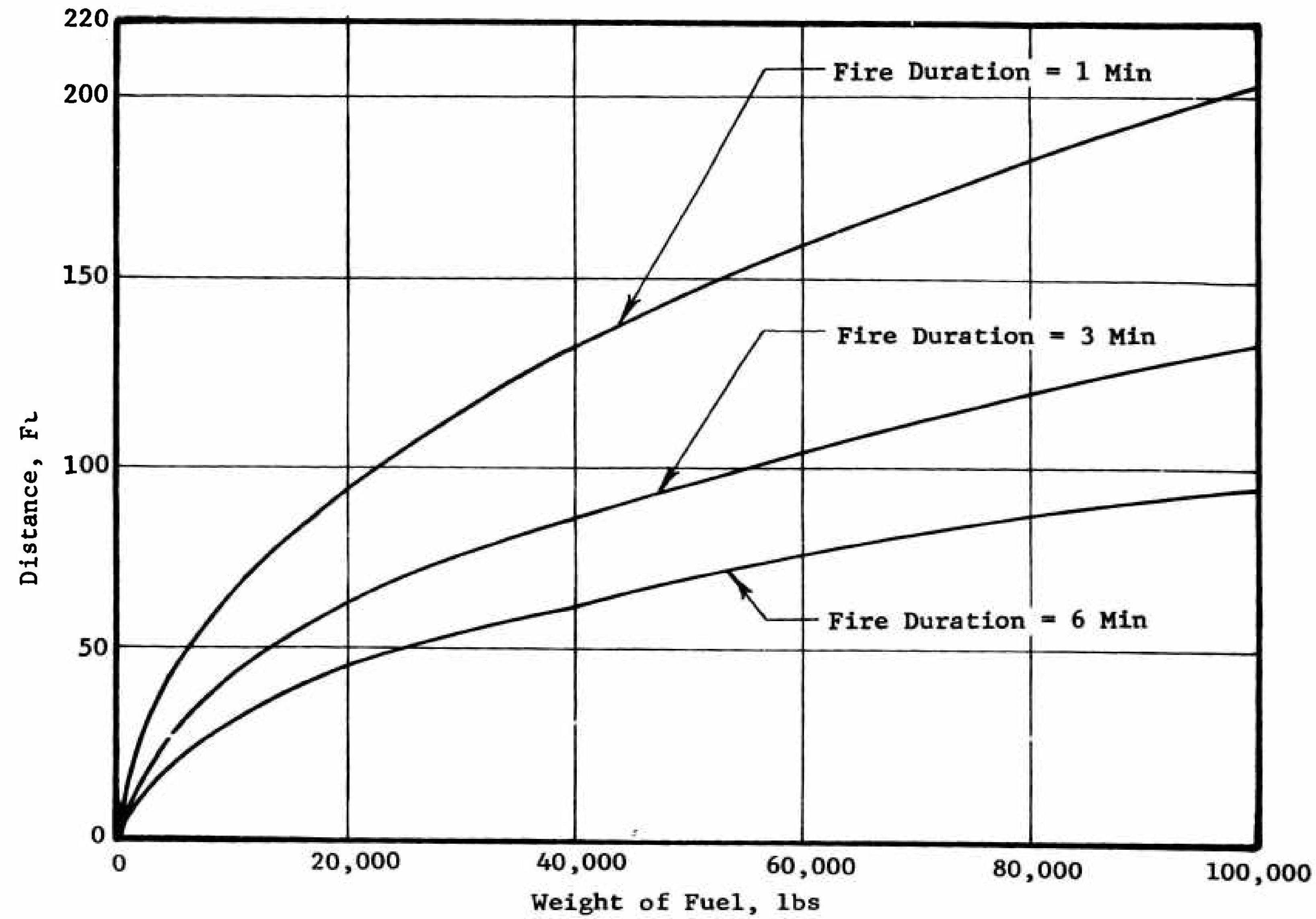


Fig. 2 CRITICAL DISTANCES OF BUILDINGS WITH WINDOWS FROM SOLID-FUEL FIRES

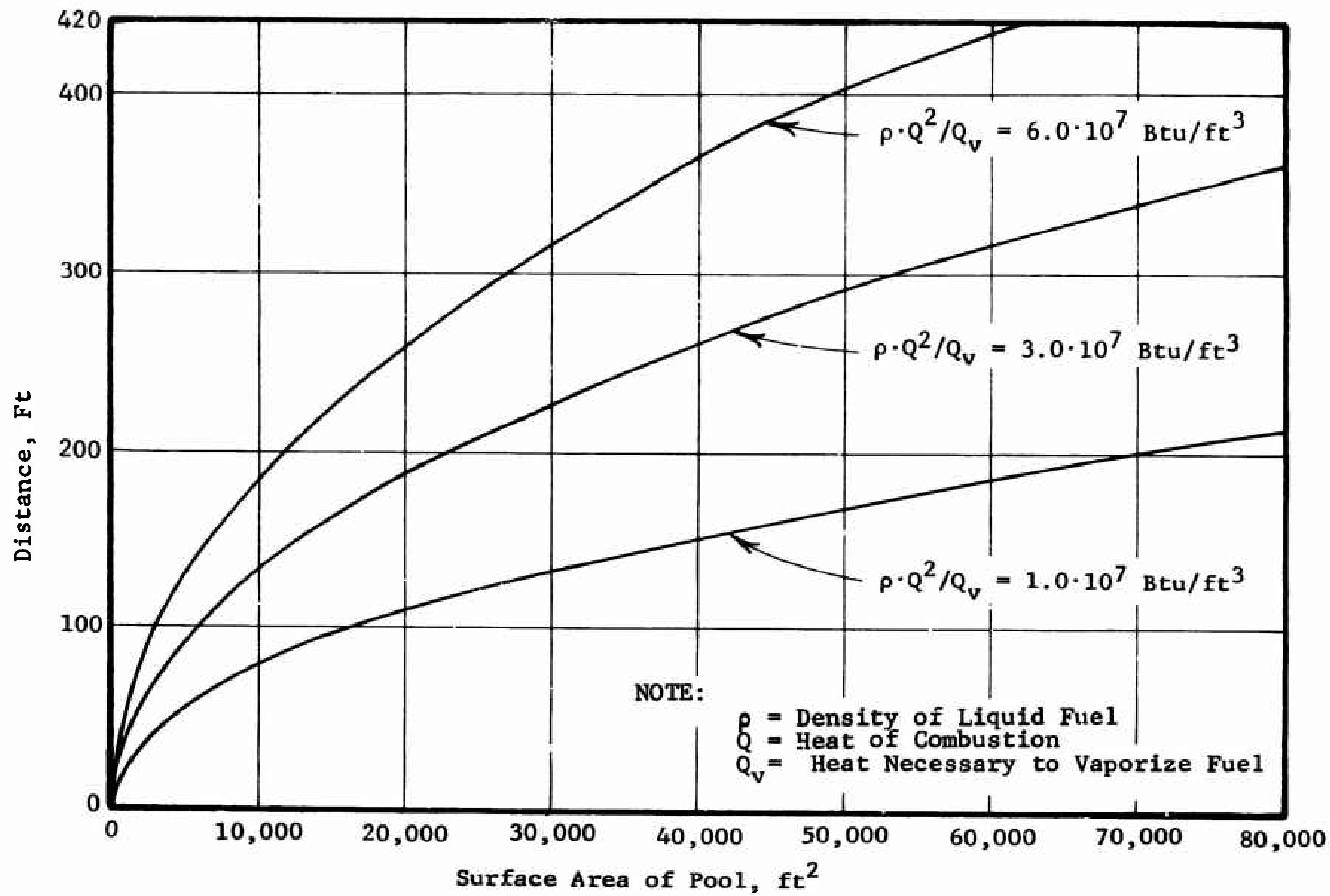


Fig. 3 CRITICAL DISTANCES OF BUILDINGS WITH WINDOWS FROM FIRES INVOLVING POOLS OF LIQUID FUEL

REFERENCES

1. Zabetakis, M. G., and D. S. Burgess, "Research on the Hazards Associated with the Production and Handling of Liquid Hydrogen," Report of Investigations 5707, Dept. of Interior, Bureau of Mines, 1961.

2. Yates, H., "Total Transmission of the Atmosphere in the Near-Infrared," Naval Research Laboratory Report 3858, September, 1951.

3. Takata, A. N., "Study of the Behavior of Systems Containing High Explosives when Subject to Fire (U)," IIT Research Institute Final Report for DASA, DASA Report Number 1833, July 1966.

4. DOD Ammunition and Explosives Safety Standards, DOD 4145.27M, Department of Defense, Office of the Assistant Secretary of Defense (Installations and Logistics), March 1969.

EXPLOSIVES HAZARD CLASSIFICATION PROCEDURES
(TB-700-2)

Moderator:

W. P. Henderson
Edgewood Arsenal, Md.

REMARKS BY E. E. HARTON, JR.
Office of Hazardous Materials
Department of Transportation
Washington, D. C.

My first encounter with TB 700-2 was in its embryonic stage at Bob Herman's Minimum Test Critiera Work Group meeting the week after President Kennedy was inaugurated. As a result of the efforts of that Work Group, TB 700-2 came into existence. Initially, I was representing the Air Force (1961-62); subsequently, I represented NASA (1962-68), and more recently, the Office of Hazardous Materials--Department of Transportation. In addition to the Military Departments and NASA, the Bureau of Explosives, as well as the Interstate Commerce Commission had representation on the Work Group.

I must admit that my understanding of DOT Hazardous Materials Regulations is considerably greater now than it was at that particular time. Of necessity I have had to learn these Regulations. I can assure you that I fully realize just how complex these Regulations are and their deficiencies.

I also understand why it was not possible for the ICC then and DOT now to buy off automatically on the criteria that the Work Group developed as TB 700-2 or any future revisions either. There are very definite rule-making procedures which must be followed irregardless of the desirability of adopting particular classification methods.

We are moving toward a single or at least a uniform classification system and corresponding test procedures for DOT, DOD and the UN Organization. The Office of Hazardous Materials and the ASESB are working closely together informally to try to bring this about. Yours truly and Bob Herman have directed assignments to lay the groundwork. It should be recognized that even though there may be informal agreement on the technical aspects, it will take some time to accomplish the desired changes through the regulatory process; and the final product (Regulation change) might be some compromise.

We expect that the technical agreement would go smoothly providing we can establish a sound, legally-defensible classification system. That is why the content of TB 700-2 is so important. It is intended for storage, handling, and transportation. Let's face it! It is not realistic enough for the latter in the area outside of conventional explosives, and not completely so in that regard.

DOT originally intended to reference this document in the Regulations. This requirement was removed from the proposed rulemaking because the Bureau of Explosives did not have a written set of test procedures which could be referenced. It is my understanding that DOD does use TB 700-2 for determining the classification of new explosives and explosive items.

Basically, the difference between the DOT classification system and that of the DOD approach and the UNO system is that DOT does not separate true mass-detonating materials from those which progressively detonate.

Specifically, with respect to TB 700-2, I believe the following would be worth considering when its revision is undertaken:

a. True mass-detonating materials vs progressive detonating/fragment-producing materials.

b. Super fire (firebrands) vs. substantial fire-producing materials.

c. Similarities and differences between firebrand producers (e.g. solid rocket propellants) and progressive detonating materials .

d. The relationship and/or distinguishing features between propellants, oxidizing materials, explosives and pyrotechnics.

e. Clarification of Class C explosives (e.g. blasting cap dilemma)

f. Tests that relate to confinement.

g. Meaningful guidelines for classification by analogy.

h. Sub-scale critical geometry test for solid propellants/ rockets.

i. Improved specifications for test materials (e.g. hardness of steel witness plates)

j. Impact sensitivity based upon reproducible non-human measurements.

k. Susceptibility to initiation (electrostatic or electromagnetic influence)

l. Establishment of an integrated peak over pressure-impulse duration base line.

m. Tests with both liquid and solid applicability (e.g. heavy confinement detonation and/or burning under pressure)

n. Terminology better than TNT equivalency.

In my opinion, we definitely need to determine the inherent hazards of materials as well as the hazards of the item as shipped.

The ideal would be to have absolute tests, but this is certainly not the present case. Therefore, we have to rely on comparative tests. We must still have some damage/injury yardstick to compare our results. I believe that an energy-time function is the common denominator that we should keep in mind and toward which we should direct our classification and test development efforts.

In case there are those in the audience who do not know it, we have a small contract with the Safety Research Center of the Bureau of Mines. The purpose is to obtain recommendations as to hazard classification test procedures in the areas of reactive chemicals such as water-reactive materials, oxidizing materials, and flammable materials. It does not involve at the present time explosives. If anyone is interested in knowing more about this particular project, I shall be happy to talk to them following this session.

It has been a real pleasure participating in this session. Thank you for your kind attention.

INADEQUACY OF TB 700-2 TESTS AS APPLIED TO PYROTECHNICS

J. F. Voeglein, Jr.
Edgewood Arsenal, Md.

ABSTRACT

The application of the US Army Technical Bulletin 700-2 (TB 700-2) tests during Phase I of the Edgewood Arsenal Pyrotechnics Hazard Classification and Evaluation Program has revealed that they are inadequate for such application because they are designed to measure explosive parameters of detonable materials. Therefore, these tests do not reveal the true hazards of pyrotechnics which are of a much lower order of magnitude than those of explosives. The subsequent phases of the test program must include the development of exact test procedures which will identify and measure the true hazardous characteristics of the specific compounds of interest. The end item tests have proven more valid but require some refinement with the inclusion of implicit standards for evaluating the results. One serious omission is the absence of scaling for the degree of hazard demonstrated by the intensity and magnitude of the conflagrations generated by the tests. The need for a method of evaluating the effect of the cargo conveyance configuration on the magnitude of the hazard has also been demonstrated.

The Edgewood Arsenal pyrotechnics hazards classification and evaluation program phase 1, segment 1, which entailed the classification of certain pyrotechnic compounds in the bulk granular state and the finished end items by subjecting them to the tests prescribed in U.S. Army Technical Bulletin 700-2 (TB 700-2), has proved these tests to be inadequate. A contributory factor to this finding is the apparent basic premise that all pyrotechnic compounds may be detonable. Therefore, the tests for explosives were applied to all pyrotechnics without benefit of proof by test.

The test to determine the probability of detonation in free air is evaluated by measuring the deformation (mushrooming) of the lead cylinder at the end supporting the sample. A two inch cube of the sample material is placed on top of the cylinder and initiated by a blasting cap contained in a two inch diameter cylindrical wood block placed on top of the sample. The test does not lend itself to testing and evaluating granular materials, neither does it provide standards for evaluation of degrees of distortion of the lead cylinder if a detonation did occur.

The ignition and unconfined burning test is performed to determine the probability of the test material propagating burning or deflagration to a detonation. This test is evaluated by determining whether a detonation took place and by recording burning time in seconds. Again there are no standards of measurement upon which to base a quantitative evaluation of the hazard. The results of these tests only verified that the test material burned at a designed rate, the function which it is intended to perform. This test also does not provide for testing granular samples. The requirement for a two inch cube of material makes it apparent that it is intended to test either cast solid propellant or preformed high explosive.

The impact sensitivity test is the most inconclusive of tests applied. It may be valid when applied to explosives which are generally homogenous compounds. The probability of obtaining a representative sample of a bulk granular pyrotechnic compound in the size used in this test (10 miligrams) is infinitesimally low. It is possible to obtain a sample that consists of only fuel and oxidizer which will detonate but is not representative of the total mixture. Conversely, it is possible to obtain a sample which does not contain any of the reactive ingredients and is also not representative. Furthermore, the results are determined by the human senses of sight, sound, and smell and not

mechanical or instrumental means which further negates the validity of this test to measure hazardous characteristics of the pyrotechnic compounds with which we are concerned.

The card gap test is performed to determine the sensitivity of the material to detonation under an explosive shock wave. The test set-up consists of a steel plate six inches square by 3/8 inches thick supported on a small wood frame six inches above the ground surface. The sample is placed in a 1 7/8 inch steel tube 5 1/2 inches long which is vertically mounted on four pieces of 1/16 inch plastic material over the center of the steel plate. Two pentolite pellets two inches in diameter cylindrical wood block with a 0-2 blasting cap inserted in a center hole is placed on top of the pentolite pellets with the end of the cap touching the top pellet. Detonation is indicated when a clean hole is cut in the steel witness plate. The fact that the witness plate is only deformed in the pyrotechnic tests tends to confirm the relative stability of the pyrotechnic compounds. Because detonation does not occur with the types of pyrotechnics tested in this program, the sensitivity measurement is possible. Card gap tests run with an empty sample tube showed greater distortion than any of the samples tested. Conversely, ordinary sand tested in the card gap configuration exhibited little or no distortion of the witness plate. Therefore, it can be concluded from these results that the pyrotechnic material only serves to attenuate the blast pressure wave front.

Some significant conclusions to be drawn are:

a. The tests now required for classification by TB 700-2 are not adequate for classifying the characteristic hazards of bulk granular pyrotechnic compounds. Therefore, different tests should be devised to provide the data upon which to base a proper classification.

b. Tests are required that will intentionally produce hazardous reactions, thereby providing a basis for measuring the true damage potential, i.e., the capability to cause destruction by means of explosion or fire.

c. The tests prescribed to determine storage and transportation classifications of pyrotechnic end items are adequate if slight modifications are made to apply them to items which do not detonate. A significant finding in the end item tests was the fact that the individual packaging of items prevents propagation within the container from one item to the other, whereas, items not individually packaged showed total propagation in all A and B tests.

There is no means provided in the external heat test of packaged end items to evaluate the intensity and magnitude at the conflagration. Therefore, the significance is not relatable to a classification, e.g.,

is the item to be classed as a storage class 1 or class 2. Also, no test is provided to determine the magnitude of the hazard when the burning items are initiated while confined in a freight car or truck. When in this configuration, the end result could be an explosion. The classification, therefore, may be more than that developed by the external heat test.

REVIEW OF EXPLOSIVES HAZARD CLASSIFICATION PROCEDURES: ARMY TECHNICAL BULLETIN 700-2

G. Weingarten
Picatinny Arsenal
Dover, New Jersey

It is the intent of Army Technical Bulletin, TB-700-2, to assure that all DOD components use identical test procedures when determining the hazard classification of ammunition, explosives and propellants. Based on the results of these tests assignments of appropriate hazard classification such as quantity-distance class, storage compatibility group, ICC class ICC markings would be made. Criteria for classification would be based on evidence of burning or detonation of the composition when initiated by shock, heat, or impact. Chapter 3 of the subject document details test procedures for determining the hazard classification of bulk ammunition prior to shipment as well as their stability and sensitivity.

Based on the experience of the Pyrotechnics Laboratory at Picatinny Arsenal with over thirty typical pyrotechnic compositions such as illuminants, delays, igniters and smokes, it is believed that the prescribed tests are not directly applicable to pyrotechnics. The Thermal Stability Test (3-10) is unnecessary as all pyrotechnic compositions must be stable at 170°F for periods up to a year before they are considered satisfactory. It is doubtful that a pyrotechnic composition will detonate without confinement, therefore the Detonation Test (3-8) and Unconfined Burning (3-9) are not suitable especially with the small sample size used. The Card Gap Test (3-12) is not applicable to pyrotechnics, since it was developed for materials that detonate. The value of the Impact Sensitivity Test (3-11) is questionable for storage and transportation.

It is suggested that these tests be replaced with procedures in which a relatively large quantity of composition (100-200 grams) are heavily confined and initiated. The confined item should be instrumented to obtain ignition temperature and pressure. Detonation rates should also be determined. Those compositions that appear to detonate should be tested for TNT equivalency for damage evaluation.

HAZARDS OF PLASTIC PACKAGING MATERIALS

Moderator:

Anthony F. Sliwa
Naval Ordnance Systems Command
Washington, D. C.

HAZARDS OF PLASTIC PACKAGING MATERIALS

Introduction

A. F. Sliwa
Naval Ordnance Systems Command

Hazards from plastic packaging materials in explosives handling operations occur both to explosives which can be detonated from electrostatic discharge and to personnel handling the material (for example, the uncontrollable reflex which makes a person jump when he receives a static shock can be dangerous in certain critical areas). Hazards to ordnance and personnel may also arise from the inadvertent burning of plastics, both from heat and noxious combustion products.

Mr. Gordon Mustin of the Naval Ordnance Systems Command, Packaging and Handling Division sums up the status of plastic packaging as follows:

"With plastics, there is doubt that we can ever achieve absolute safety. We cannot turn the clock back for we are in the age of plastics. To ban these materials out of hand is simply to abolish the ammunition distribution system; thereby destroying our nation's ability to fight".

To repeat, safety problems with plastics are basically:

a. Static Electricity

b. They burn

Fortunately, some progress is being made in this field and the following papers will provide an indication of the state of the art.

CONCLUSIONS

As a result of discussions after the talks, it was concluded that a definite electrostatic hazard exists to some munitions packaged in untreated polyethylene barrier bags or untreated polystyrene.

Further, a recommendation was made to include requirements for conductive plastic packaging materials for ordnance in the appropriate ordnance safety manuals, such as the Navy's NAVORD OP 5.

There was a general consensus that an open symposium, possibly sponsored through the National Security Industrial Association or American Ordnance Association, could contribute to greater understanding of the "plastics for packaging" problems.

REMARKS BY P. J. SMITH
Naval Ammunition Depot
Crane, Indiana

The following remarks are made from the position of a packaging engineer interested primarily with the packaging of ordnance items, rather than the handling of raw or loose explosive and pyrotechnic composition.

NAD Crane has developed and utilized a number of plastic containers and materials for packaging pyrotechnic and explosive items. The plastic materials have included beaded styrene, foam urethanes, and plastic films of all types.

Before we can discuss the hazards of plastic packaging materials, we must take a brief look at the items we are packaging, their strengths, and potentially dangerous characteristics.

For example - the MK 25 Marine Location Marker or the M17A1 Ground Illumination Signal are pyrotechnic devices having complete metal bodies. By this, I mean there are no openings or electrical ignition points exposed during shipping or handling.

Such a metal encapsulated device isn't susceptible to accidental initiation by static electricity. In fact, we have discharged a Van der Graff generator into the MK 25 at various points with no effects. Therefore, the static charge which could be generated by plastic packaging materials are unobjectionable to such metal encapsulated ordnance.

However, we recognize that it would be unsafe to tolerate the build-up of large static charge on ordnance packaging simply because the contents were resistant. This would ignore the hazard to other items in mixed shipments. Therefore, we take the precaution of requiring an antistatic coating on the containers to prevent the buildup of static charges.

This type of packaging would not be adequate for loose composition or electrically initiated detonators.

Obviously the type of plastic packaging must be matched to the material or ordnance being packaged and its intended life or distribution.

The other members of the panel have covered the fundamental hazard of static electricity, the progress of developing static free film, and the hazards of hydrocarbon blowing agents.

I would like briefly to touch on just three areas and outline some of our experiences at NAD Crane. The areas are:

I. Foam Styrene Containers - their long term physical performance.

II. The long term performance of the antistatic coating on styrene.

III. The fire retardant foam study program currently underway at NAD Crane.

DISCUSSION:

I. The initial design of a plastic container must insure that adequate strength is provided to protect the ordnance. The hazards of drop and rough handling must be overcome by the design, the plastic material chosen and the manufacturing technique used to mold the unit.

Our experience has shown that some molders do a better job of welding the material together, thus making a stronger container. These units do withstand long term exterior storage. Containers have had 6 years outside, unprotected storage at Indiana without serious deterioration. Exposure under tropical conditions for 2 years has not shown any potential failure.

II. Antistatic Coating

How do antistatic coatings for styrene survive long term storage? The answer is they last as long as necessary. The coatings on the inside surfaces which are protected from the sun appear to stand up indefinitely. The coatings on the outside surfaces, exposed to the sun, gradually disappear. However, the nature of the surface changes. The flat surface of the styrene beads are broken down and the jagged cell side walls remain. Apparently these thin vertical walls do not facilitate the accumulation of static charges or dissipate any charges as quickly as they build up.

The net result is that the antistatic coatings on foam styrene have performed satisfactorily as long as needed.

III. NAD Crane is currently conducting an exploratory development program, funded jointly by the Navy and the Air Force, on fire resistant phenolic foam. The foam with a number of various fillers appears to overcome the traditional brittleness of phenolics.

To date, a 1 inch thickness of foam withstands 2000°F for 1 hour without serious buildup of heat on the inside surface. The foams are being mixed on production type equipment in batches. The program should provide design parameters for fire resistant ordnance packaging in approximately one year.

I hope these remarks have presented a slightly different viewpoint about plastic packaging materials for ordnance.

SENSITIVITY CONSIDERATIONS FOR PLASTIC PACKAGED ORDNANCE

John T. Petrick
Naval Weapons Laboratory, Dahlgren, Va.

INTRODUCTION

The free electron and band theories of solids lead to a better-than-ever electrostatic theory. Contact charging can now be explained, at least qualitatively, by using these theories and invoking insulator surface states.[1,2,3] This modern theory explains many heretofore anomalous charging effects, however, the theory has not yet led to any new methods of electrostatic hazard mitigation.

Safe packaging of ordnance must still be ensured by using the conductive or antistatic plastics, both of which simply increase the conductivity of the packaging material thus permitting rapid charge neutralization. The choice of antistatic or conductive plastics may be made from a knowledge of the electrostatic sensitivity of the ordnance and the resistivity of the plastics under consideration.

Ordnance sensitivity must be obtained by testing except in the few cases in which design features provide an obviously safe item. Sensitivity tests for ordnance must be tailored to the class of item undergoing test. For example, an ordinary electroexplosive device (EED) requires tests of pin-pin and pin-case firing modes whereas a weapon component may not have any external leads or pins, and therefore will require a special test procedure.

The sensitivity tests may demonstrate that the ordnance is very sensitive. Then an electrostatic fix may be recommended, or if a fix is not feasible, the ordnance may be restricted in handling and be packaged in a highly conductive material to prevent an electrostatic hazard.

SENSITIVITY AND FIRING MODES OF EED's

EED's are available in several varieties such as the hot wire type, the carbon bridge type, the exploding bridge type (EBW) and the conductive mix type. The basic configurations used are shown in figure 1.

Sensitivity of the EED's differ considerably with the EBW being the least sensitive. The conductive mix and the carbon bridge types are the most sensitive, and the hot wire type may have a wide range of sensitivity depending on design.

The modes in which an accidental electrostatic initiation can occur for the EBW and hot wire type are essentially similar. These modes are shown in figure 2. The firing modes for carbon bridge types are shown in figure 3. There is only one mode for firing the conductive mix EED's and it is shown in figure 4.

MIL-I-23659 Initiators, Electric, Design and Evaluation of, may be used to evaluate EED's for electrostatic safety. Care should be taken not to increase the inductance of the discharge circuit over the value consisting of the human circuit of figure 5. Excessive inductance slows pulse duration and lowers peak current, thus allowing a sensitive EED to pass the test.

SENSITIVITY TESTS FOR WEAPONS AND WEAPONS COMPONENTS

The possible increase in sensitivity of weapons and weapon components over the sensitivity of the EED's used requires a test of the weapon or component itself. The sensitivity test table shown in table 1 is a preliminary version of a table to be included in an electrostatic design guide presently in preparation. Table 2 shows the test procedures called for in table 1.

The sensitivity test table is used as follows: A particular weapon or component is to be evaluated for electrostatic hazard. The following questions are then answered:

(1) Is the case of the internal EED grounded?

(2) Are the internal parts conductive? grounded?

(3) Are there any external leads going to the EED?

(4) Is there an internal electronic firing circuit?

(5) Are there external leads running to the internal electronic firing circuit?

(6) How much (percentage) area of the outer surface is conductive?

Answers to these questions will yield a test method for the weapon or component. If there is more than one EED in the weapon or component, the test which has the highest letter (closest to A) should be used. For example, the fuze-warhead shown in figure 6 is to be evaluated. The answer to each question is as follows:

(1) yes

(2) yes, yes

(3) no

(4) yes

(5) yes

(6) 55%

Thus the sensitivity test should be the B test which is a 500 pf capacitor charged to 25,000 volts discharged through a 5,000 ohm resistor and no more than 6 feet of connecting wire. The discharge is applied to all combinations of external leads and metal weapon case. This configuration is rated 3 on susceptibility, thus it is quite susceptible.

ELECTROSTATIC TESTS FOR PLASTIC PACKAGING MATERIALS

The resistivity tests seem to be the most reliable methods for determining the electrostatic propensity of plastics. Most of these tests involve charging the sample to a high voltage either by triboelectric charging or power supply charging and allowing the sample to discharge through the air and grounded conductive clamps. These tests are conducted under controlled temperature and relative humidity conditions. The discharge rate of the sample is then compared to the rates of known antistatic or conductive materials. If the sample takes a longer time to discharge, its resistivity is high and it is less than satisfactory. If the sample discharges more quickly, it is considered acceptable.

Since the position of materials on a triboelectric series is no indication of the charge produced when materials are contacted,[1] there is little if any benefit to be gained from triboelectric charging in these tests.

REFERENCES

1. Montgomery, D. J., "Static Electrification of Solids", Solid State Physics, Academic Press, N. Y. 1959 Vol. 9, pp. 139-197

2. Gonsalves, V. E., "Some Fundamental Questions Concerning the Static Electrification of Textile Yarns: Part I", Textile Research Journal, October 1953, pg. 711

3. Van Ostenburg, D. O. and Montgomery, D. J., "Charge Transfer Upon Contact Between Metals and Insulators", Textile Research Journal, January 1958, pg. 22

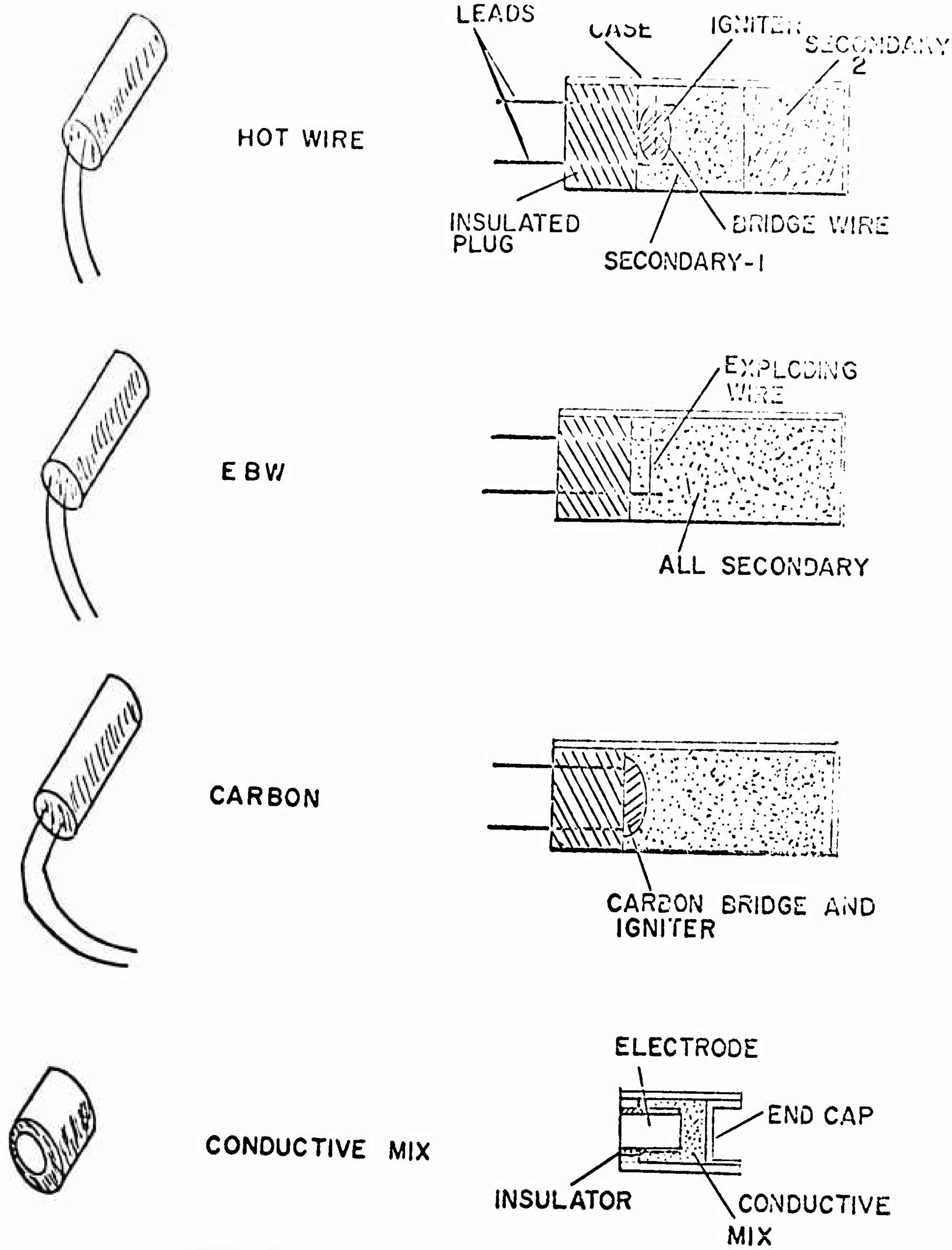


FIGURE 1: EED CONFIGURATIONS

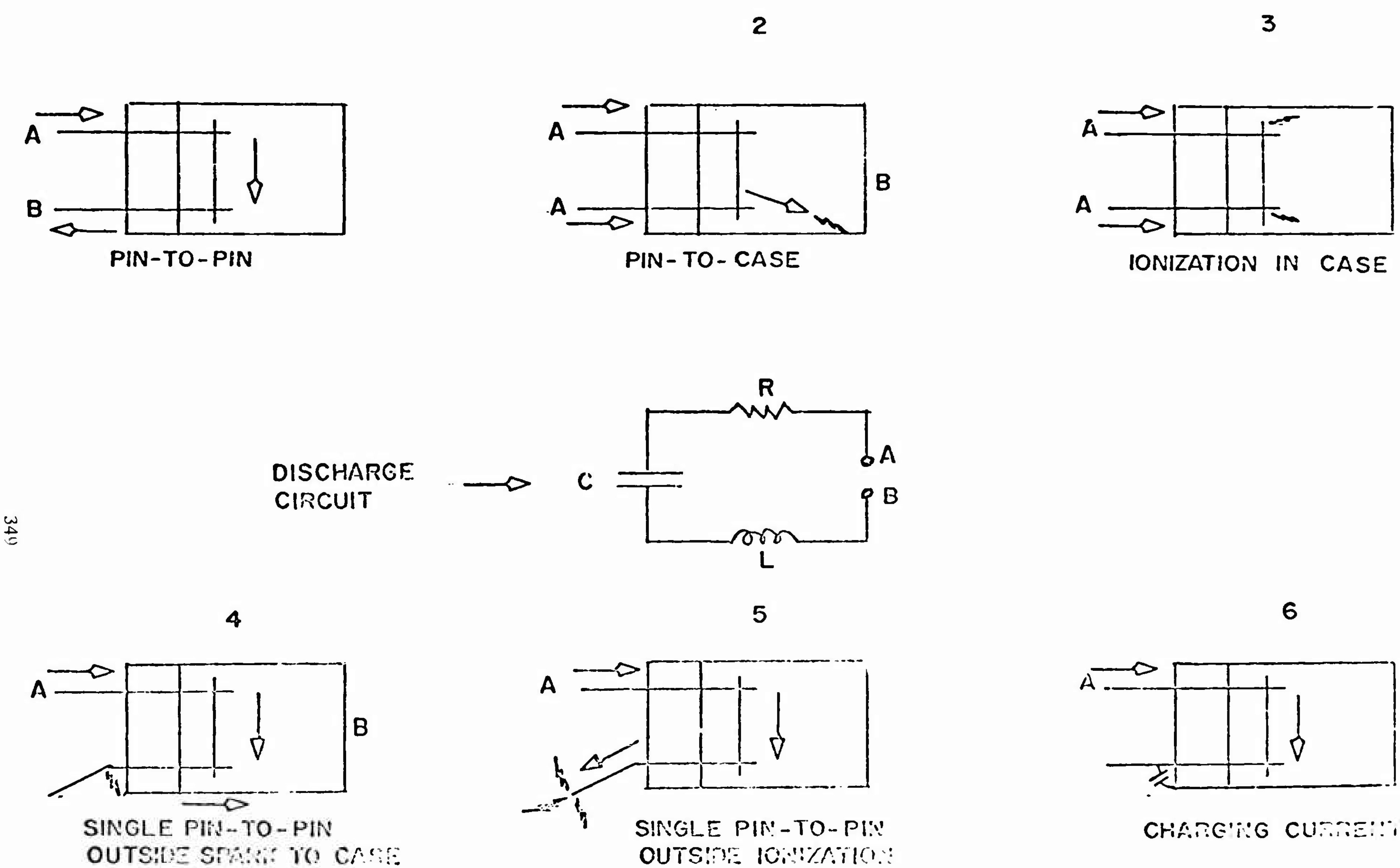


FIGURE 2: ELECTROSTATIC FIRING MODES FOR HOT WIRE AND [illegible] TYPE EED

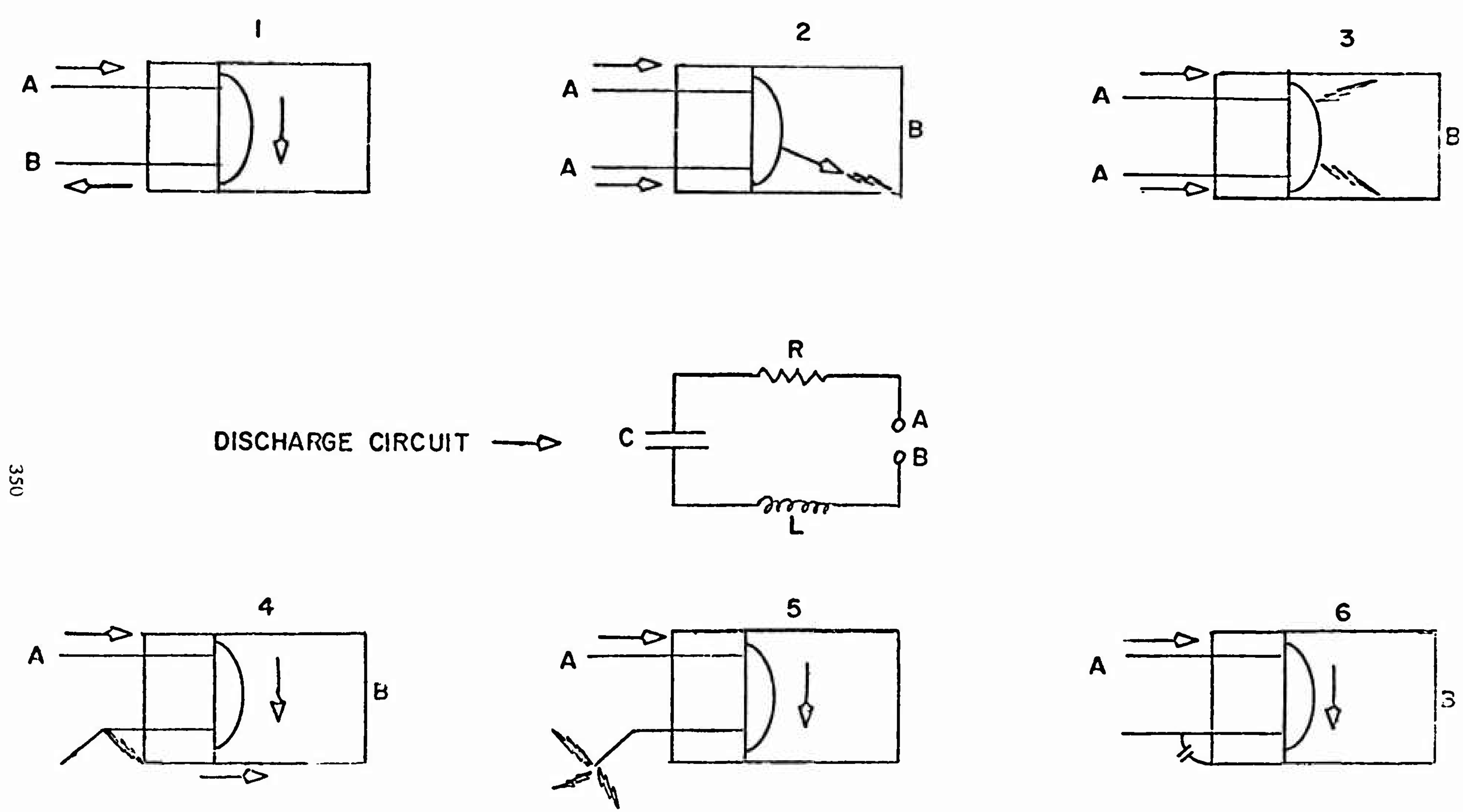


FIGURE 3: ELECTROSTATIC FIRING MODES FOR CARBON BRIDGE EEDS

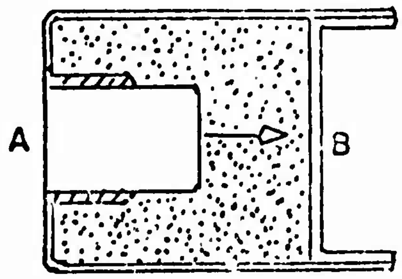


FIGURE 4: ELECTROSTATIC FIRING MODE OF CONDUCTIVE MIX ESD

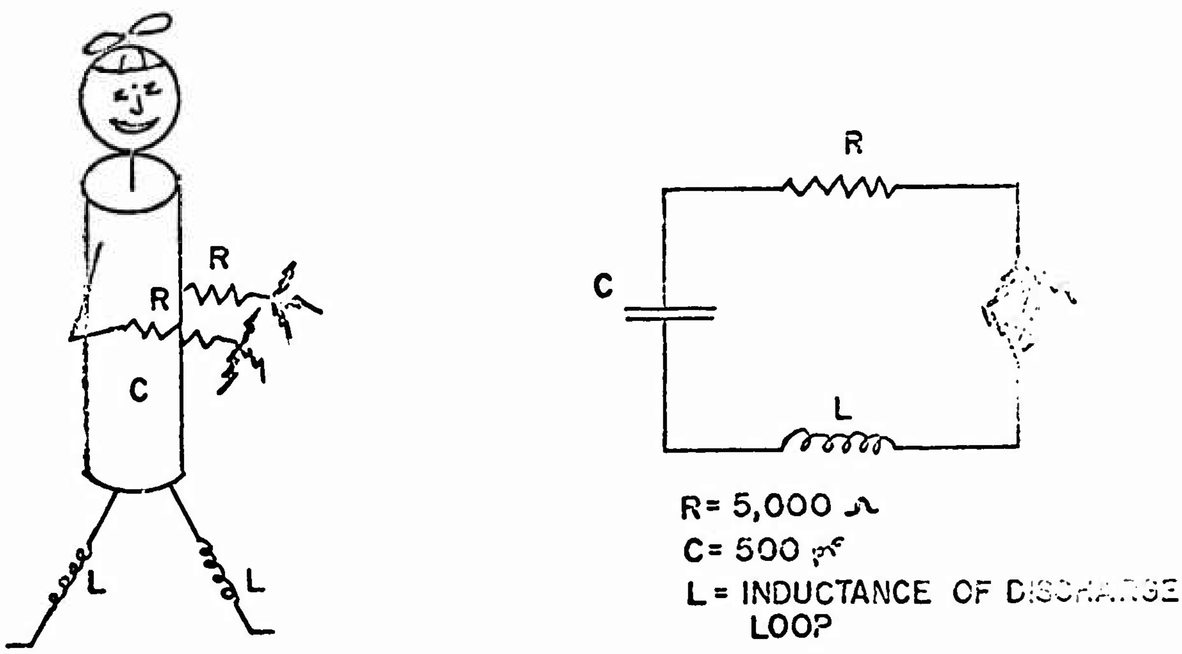


FIGURE 5: HUMAN DISCHARGE CIRCUIT

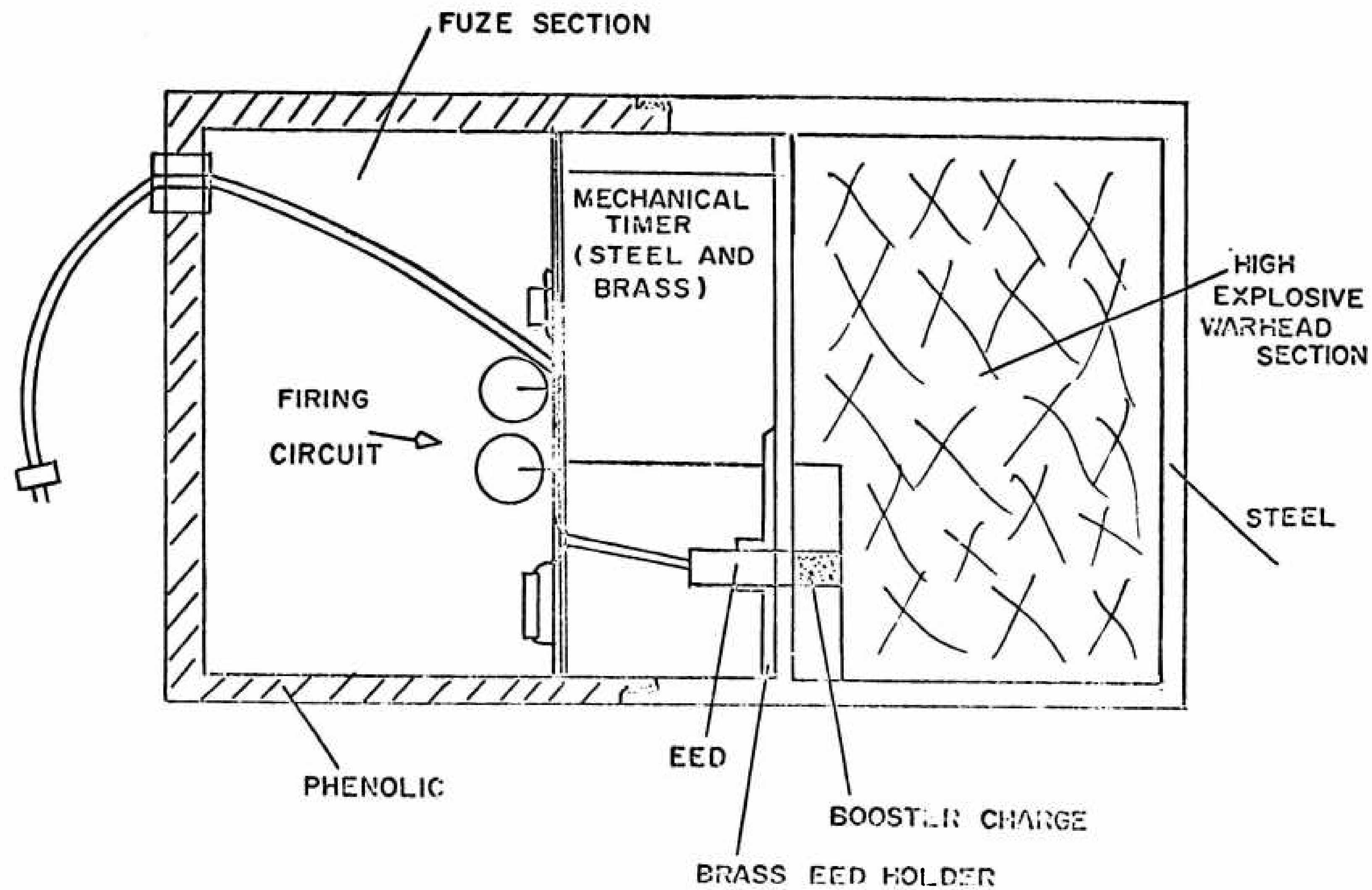


FIGURE 6: FUZE-WARHEAD EXAMPLE

TABLE I. SENSITIVITY TEST TABLE FOR WEAPONS AND WEAPON COMPONENTS

EED CASE STATUS [1]	insulated			insulated			insulated			grounded			grounded			grounded		
INTERNAL PARTS [2]	conductive ungrounded			conductive ungrounded			insulated			conductive ungrounded			conductive grounded			insulated		
EXTERNAL LEADS TO EED	YES	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO
INTERNAL ELECTRONIC FIRING CIRCUIT	NO	YES	YES	NO	YES	YES	NO	YES	YES	NO	YES	YES	NO	YES	YES	NO	YES	YES
EXTERNAL LEADS TO INTERNAL ELECTRONIC FIRING CIRCUIT	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO	YES	NO	NO	YES
SENSITIVITY TESTS REQUIRED: % Shielding [3] 0%	A	D	C	—	—	—	A	D	C	—	—	—	—	—	—	—	—	—
0% - 50%	E	D	E	E	D	E	E	D	E	A	D	E	A	D	E	A	D	E
50% - 90%	B	D	B	B	D	B	B	D	B	A	D	B	A	D	B	A	D	B
90% - 100%	B	D	B	B	D	B	B	D	B	A	D	B	A	D	B	A	D	B
100%	B	F	B	B	F	B	B	F	B	A	F	B	A	F	B	A	F	B
SUSCEPTIBILITY [4]	2	1	2	2	1	2	2	1	2	3	1	3	3	1	3	3	1	3

(1) "grounded" means grounded to conductive weapon or component housing

(2) Internal parts which could provide a discharge path, eg. timer, propellant grain, fuze, high explosive, etc.

(3) "% Shielding" is the ratio = $\frac{\text{Conductive Surface Area}}{\text{Total Surface Area}} \times 100$

(4) 1 Less Susceptible
2 Moderate Susceptibility
3 More Susceptible

Opinion based on relative magnitude of hazard without any knowledge of EED sensitivity

TABLE 2. ELECTROSTATIC SENSITIVITY TESTS FOR GENERAL HANDLING SAFETY*

Test	Circuit	Method**
A	Conduct both tests B and D listed below.	
B	Series Circuit of: 500 pf capacitor, 5000 ohm resistor, 2-4 μh circuit inductance. 25,000 volts on capacitor.	Discharge series circuit through all combinations of external leads and conductive portions of item.
C	Same as B circuit	Discharge series circuit through all combinations of external leads. Place item on grounded metal plate and discharge series circuit to all sensitive points *** on the insulated item case.
D	Same as B circuit	Place item on grounded plate and discharge to all sensitive points *** on the insulated item case.
E	Same as B circuit	Discharge to all combinations of EED leads and case. (Test done on EED only)
F	No test required	

* Special electrical circuits must be used for other situations such as a charged helicopter.
** Each test will be conducted 12 times. New EEDs must be installed between tests.
***"Sensitive points" are those points where internal parts or wires, lie closest to the surface of the item. Also include any points which are easily accessible to handling personnel, (eg. hand operated triggers, carrying handles, etc.)

FIRE HAZARDS OF PLASTICS

Emil Thomas
AFLC, Wright Patterson AFB

Man has long sought the means of combating fire which down through the ages has deprived him of his possessions and frequently his life. His first attempts were through methods of control. More recent efforts have been concentrated toward the development of more flame and heat resistant materials.

Flame resistance in plastics is achieved by compounding flame retardants either by mechanical blending or by chemical combination into the basic polymer structure.

With the mechanism by which flame retardants function not clearly understood, improvements in the flame resistance of plastics are largely empirically achieved.

The fire hazard of a material is a function of flammability, flash temperature, ignition temperature, flame intensity, products of combustion, and perhaps other characteristics. No single test or series of tests has been developed to date capable of assessing completely the hazards of a material in an unscheduled fire. Nevertheless, the determination of contributing characteristics can provide valuable information.

Flammability tests commonly used consist of igniting a standard size specimen and determining the time required for extinction of the combustion reaction.

The oxygen index method for determining the relative flammability of plastics was introduced by Fenimore and Martin in 1966. It was adopted as an ASTM standard in the early part of 1970. The oxygen index of a material is the minimum volume percent oxygen in a mixture of oxygen and nitrogen which will just support combustion in a candle-like manner. The method is reported to be reproducible to within 1% for materials with indices 21 and below and within 3% for materials with indices above 21. Materials classified as slow burning by other methods correspond to oxygen indices of 20-27. Those classified as self-extinguishing correspond to indices of about 27 and above.

As fire hazards, plastics are no worse than many other materials. Ignition temperatures range from about 700°F to 1400°F as compared to paper and some wood products in the neighborhood of 500°F. Most plastics have flammability ratings of slow burning to self-extinguishing.

More than 50% of building fire fatalities are reported to result from the effects of smoke and toxic combustion products. Many authorities feel that the dangers from carbon monoxide are far greater than from other toxic decomposition products. In carbon monoxide production, plastics are probably no worse than cellulosic products.

Though considerable effort has been devoted toward the development of flame and fire resistant plastics, much remains to be done. Greater emphasis is required on research of a fundamental nature and development of better test procedures.

ELECTROSTATICS AND NEW PACKAGING MATERIALS

BY

IRVING H. CUSTIS
NAVAL AIR DEVELOPMENT CENTER
WARMINSTER, PENNSYLVANIA 18974

Static electricity which was once a laboratory curiosity is now a problem with the expanded use of transparent thermo plastic materials in the form of flexible barriers around missiles and other electrosensitive devices as protective wraps. These materials are insulators and will generate and retain very high electrostatic charges, therefore, they should be modified so that they will be safe for these applications. The Naval Air Development Center initiated a program to modify the presently available material through the use of internal antistatic agents. The initial effort was directed towards developing a test procedure for evaluating the performance of these agents. The procedure is listed as Method 4046 in the Federal Test Method Standard 101b.

Numerous materials were evaluated, such as fatty acid derivatives, amines, diamines, pyridines, metal phosphinates, metal pigments, sulfonated compounds and phosphated esters, which are only a small portion of the materials tested. These materials were milled in low density polyethylene and the electrostatic properties of the modified polyethylene was determined in accordance with Method 4046. Any material that dissipated a 5000 volt charge in one second or less in a desiccated atmosphere was considered satisfactory. Two materials, one amine and one phosphated ester exhibited satisfactory electrostatic properties. However, they are affected by

direct impingement of water and degraded by ultra violet radiation. Work is in progress to produce an antistatic free film which will not be degraded by water and/or sunlight.

A Military Specification MIL-P-81705(AS), Plastic Sheets, Flexible, Electrostatic-Free, Heat Sealable, Heavy Duty For Packaging Applications, has been issued covering two tvpes of materials, Type I - transparent and Type II - opaque. An amendment to the specification changing the Type II thickness and elongation requirements has been submitted. As soon as the amendment is issued, two materials manufactured by the Ludlow Corporation, Holyoke Massachusetts, will be available under the Type II category. Work will continue in an effort to produce a transparent, electrostatic free material.

POLYSTYRENE INVESTIGATION

Robert Leonardi
Picatinny Arsenal

A report from the field describing the spontaneous ignition of foamed polystyrene during the unpackaging operation of a currently deployed munition system can be credited for the sudden attention placed upon polystyrene and its inherent volatile characteristics during its drying cycle.

From a study of the facts reported on the incident in question, it appears that the following occurred: A field operator was in the process of unpacking a munition system consisting of a wooden box which inclosed a barrier bag containing a munition component sandwiched in polystyrene. The cover was removed exposing the barrier bag. When the barrier bag was removed by the operator, he detected the presence of static electricity. He proceeded to open the bag exposing the polystyrene. At this point in the operation, when the operator proceeded to remove the polystyrene cover, a hissing sound was heard and spontaneous ignition of the polystyrene occurred.

There are, to date, many questions which have not been answered. Some of these are:

a. Did a spark occur during the barrier bag opening operation and, if so, at what stage in the operation?

b. Was the operator touching the polystyrene supports when spontaneous ignition occurred?

c. Was a spark noticed prior to combustion of the material?

In any event, spontaneous ignition did occur and electrostatic discharges were observed. Hence, one has the ingredients to support a large-scale investigation.

The primary questions to be answered were:

a. What were the flammable constituents of the atmosphere ignited and what medium provided them?

b. What caused the electrostatic build-up in the packaging system?

Beginning with a. above, it was common knowledge that pentane is the expanding agent used in the formulation of the polystyrene beads. Further, it was known that at the completion of the molding operation a pentane residue in the order of 3% by weight of polystyrene could be expected. It was normally presumed, however, that the pentane would escape during the air drying cycle. Since normal air drying cycles of five days duration could be expected between the polystyrene fabrication and the loading plant operation, it was initially assumed that the polystyrene sealed in the barrier bag was essentially a pentane free material. However, it was decided that a test program be prepared that would determine:

a. The degree of pentane loss during varying air drying cycles.

b. The extent to which flammable atmospheres could be achieved in sealed systems with polystyrene containing varying degrees of residual pentane.

With this in mind, the test program shown in viewgraphs 1 and 2 was formulated.

From the data shown on the viewgraphs, it is not difficult to understand the possibility of achieving an explosive atmoshpere in a sealed system if insufficient time is allowed for the pentane to escape.

The explosive range of pentane in air is 1.4 to 7.8% by volume of pentane to air. Theoretically, atmospheres falling within this range can be ignited by providing a spark of the right intensity, duration and magnitude. It has been established that the least amount of energy required for pentane-air atmosphere ignition occurs at the stoichiometric ratio which for pentane and air is in the 2.5% by volume range.

With the above data in mind, laboratory procedures were established that would permit the discharge of electrostatically charged polystyrene material into a jar containing the ideal pentane air ratio using needle type electrodes. Ignition could not be obtained under these conditions in the laboratory even though polystyrene material was charged to values of 20,000 volts. Sparks produced by mechanically generated high voltage levels did result in ignition. Ignition of the stoichiometric mix could also be obtained by draining the surface charge induced on anti-static treated polystyrene (coated by immersion) under ideal laboratory conditions.

When consideration was given to the levels of electrostatic engergy that were required to cause ignition under laboratory conditions, the maximum levels of electrostatic energy that have been measured in the polystyrene

supports in question, and the hundreds of thousands of munition packaging systems presently deployed, the consensus was that the hazard, if any, is probably no more tnat that which would be encountered due to the handling of the system during its transportation cycle.

Nevertheless, it was considered essential and paramount that an investigation be conducted to select a material that could be placed within a sealed packaging system that was capable of neutralizing and/or absorbing the pentane that would evolve from the polystyrene. The search ended with the selection of activated charcoal.

There are currently several grades of activated charcoal which are capable of absorbing 30% of their weight of pentane. Charcoal will retain the pentane at the temperatures encountered at the extremes of the natural environment (160°F) and can be placed in bagged systems containing desiccant without degrading its efficiency.

For example, the pack in question contained 1800 grams of polystyrene. Assuming that the polystyrene had a pentane residual level of 3% by weight, the total pentane to be absorbed - assuming no affinity of the polystyrene for pentane - would be 54 grams. Hence, 180 grams of charcoal would absorb all of the available pentane. This would be a maximum condition.

With reference to the spark producing capability of polystyrene, it has been determined that this material properly immersed in solution of

Catnax or Zelac, in preference to previously employed spraying operations, will produce surface effects that will, with a high assurance, not result in spark discharge.

P E N T A N E

PERCENT OF LOWER EXPLOSIVE LIMIT

		0	1	2	3	4	5	6	7
HOURS	0		>90 >90			>90 >90			
AT	*16				>90 >90				
130 F	*20				>90 >90				

*No measurable amount of N_2O (Dean Stark)

Note A - test program started 26 February 1970

Figure 1

PENTANE

PERCENT OF LOWER EXPLOSIVE LIMIT

DAYS IN SEALED CAN

DAYS AIR DRIED	0	1	2	3	4	5	6	7	8	9	10	11
1*				>90 >90								
2			82 >90	>90 >90								
3		30 17 40 HOURS	>90 >90									
4**		86 >90	>90 >90									
5*** 2.56		86	>90						REPACKED 14	56	>90	
6*** 2.65		74	>90									
11*** 2.09		28	48	66	88	>90	>90	>90				
15*** 1.85				66	60	68	66	16 HOURS @160 >90				
22*** 1.6				30	32	36	40				48	16 HOURS @160 72
32*** 1.54		3										

*H_2O .06 - .09% **NO MEASURABLE AMOUNT OF H_2O DETECTED (DEAN STARK) *** TOTAL VOL

NOTE A - TEST PROGRAM STARTED 26 FEBRUARY 1970

Figure 2

EXPLOSIVES EQUIVALENCIES

Moderator:

L. J. Belliveau
Defense Atomic Support Agency
Washington, D. C.

SPECIALIST SESSION ON EXPLOSIVE EQUIVALENCIES

Moderator: Mr. L. J. Belliveau
Defense Atomic Support Agency
Washington, D.C. 20305

Introductory Remarks by the Moderator:

When Bob Herman, of the ASESB, asked me to act as moderator of this session, we discussed several possible speakers and the topics to be discussed. He wondered at that time whether the title Explosive Equivalencies was the best title for the session. The title seemed appropriate to me, so we let it ride.

Bob's hesitation at the choice of title nagged at me for a while. As a long time member of the ASESB Hazards Reduction Working Group, I was well acquainted with the language gap between the explosive research scientist and the civil or mechanical engineer who designs and fabricates practical production, distribution, and storage facilities in a real world. Since both groups might use the same dictionary, I looked up equivalence in Webster's 3rd dictionary. Unfortunately, the exact meaning I wanted was missing. So I guess the gap still exists, or can't be bridged by Webster's 3rd edition anyway.

The way I understand explosive equivalence is through equivalent weight or energy. The definition that suited me the best, after a necessarily short investigation, was the following:
"The free air equivalent weight of a particular explosive gives the weight of standard explosive necessary to produce shock wave parameters(peak shock overpressure, impulse, etc.) of equal magnitude at the same test geometry."
This definition comes from a Naval Ordnance Laboratory Report, NOLTR 65-218, and it contains only 34 words, counting etc.

While this definition is shorter than the Lord's Prayer, and all the words are in the dictionary, each of the underlined words needs to be qualified and many questions can be raised. For example, how is equivalent weight in water or rock defined? or measured? or calculated? Can basically similar explosives such as the cyclotols, be validly compared to Ammonium Nitrate/Fuel Oil Explosives? Are equal pressures sufficient to make the comparison for equivalent weight, or do both overpressure and impulse have to be the same? Can spheres of explosive be compared with hemispheres, or cylinders, or cubes, with any validity?

The following speakers may not have answers to all such questions, but will, I hope, discuss them intelligently with us.

Comments by the Moderator on the sessions:

As a result of remarks made by Mr. Richard Rindner, of Picatinny Arsenal, extra emphasis was placed on the specification of the explosive standard. The speakers reported on effort that is essentially completed, with the exception of the last presentation on Air Blast from 155 mm Shell Stack Tests. Several investigators expressed surprise and interest in the results. Some of the speakers remarks are available in outline only. A summary of the session titles, speakers, and the extent of the available papers follows:

a. Watch Your Equivalent Weight Joe Petes, Naval Ordnance Laboratory (NOL)	Full Paper
b. Ammonium Nitrate/Fuel Oil (AN/FO), A Safer Air Blast Source, L.D. Sadwin (NOL)	Outline Only
c. Analysis and Correlation of Underwater Explosions Data at NOL, D.E. Phillips (NOL)	Full Paper
d. Equivalent Weights of Explosive Fill Candidates Charles Kingery, Ballistics Research Laboratory (BRL)	Outline Only
e. Comparison of TNT and Cold Castable Mixed Explosive John Keefer, (BRL)	Full Paper
f. Air blast from 155 MM Stack Separation Tests Charles Kingery (BRL)	Outline with Charts and Figures

Further information can be obtained by writing to the authors cited, within the limitations of security requirements and disclosure of proprietary information.

WATCH YOUR EQUIVALENT WEIGHT

J. Petes
Naval Ordnance Laboratory
Silver Spring, Md.

This is supposed to be an informal session, so I suppose I should provide my own soap box. I feel I could use a soap box because I have a message to import. And the message is--when you want to determine the airblast equivalent (FIG.1) weight of any particular explosion or explosive, make sure you are comparing (1) similar charge configurations, (2) similar test geometries or geometries of interest, and that you are (3) making comparisons over the same pressure range.

And one more thing, (4) make sure you indicate what you are equating to--otherwise you will not get an unequivocal answer.

That's the message. If you all accept this data, my talk is over. But on the chance that some of you may wonder why these conclusions, let me briefly go over a few details.

During the past few years particularly, I have been concerned with this thing called equivalent weight--what it means, how it is used, and how it is misused. I find that the equivalent weight concept is a good one and useful; and it is properly used quite often. But on the other hand, I find it is improperly applied quite often too--improperly applied and hence, fraught with dangerous consequences.

Researchers interested in the practical side of things--like designing a protective structure--misapply it. Safety engineers concerned with the hazards of large rocket motor explosions misapply it. Warhead designers looking for the biggest bang misapply it.

And I find the same situation prevails in industry and government--and even embarassingly sometimes at my own Lab.

My concern is that when a researcher says that a particular rocket propellent has an equivalent weight of 200% or more, that someone, NASA maybe, is going to go out and buy up all of Florida--when perhaps only 1/3 of Florida is needed.

My concern is that when another researcher says that a stack of ammunition has an equivalence of 125% that someone--ASESB maybe--will go out and build a magazine to meet this equivalence---and then find it to be inadequate.

My concern, in short, is that we'll make costly mistakes--costly in terms of money and lives.

Let me be specific. I have seen reports in which the equivalence of rocket motors based on blast data have been determined to be 200+%, and stacked munitions 125% or so. Boy, wouldn't the warhead people love to have an explosive which puts out twice as much oomph as present day warhead fills. The best we can do is get an explosive about 40% better than TNT. In other words, there is something screwy about the 200+% figure for the propellent, and as I will show, the 125% figure for the munitions.

Let's see what the equivalent weight for airblast is for the one case I studied in some detail:

The item of interest is a large rocket motor with solid propellent on the launch pad--so it's a ground burst that we are interested in. But what is a ground burst? It is only recently that we in the explosions game have really defined what we mean by a ground burst. A ground burst is one in which a spherical charge is half in and half out of the ground. That is the center of gravity of the charge is at surface level.

We found it necessary to be very specific about defining a ground burst because there is a world of difference between the pressure-distance curves for things that we previously had loosely lumped together as surface bursts.

For instance, Slide 2 compares the pressure-distance curves of several charge configurations. The comparisons are for TNT charges weighing 1 lb and resting on the surface. Notice, above the 10 psi level particularly, the wide divergence of peak pressures for a given distance between half buried spheres, hemispheres, spheres tangent to the ground and cylinders. A factor of 4 in pressure at some ranges; a factor of 2 in distance at some pressures.

Incidentally, it should be mentioned that the curve for the cylinder is for a particular cylinder--one with a length to diameter (L/D) ratio of 5 to 1. For other L/D's we would have other pressure distance curves.

This figure gives the rationale for my first point in equivalence determinations--different charge shapes of even the

same explosive material give drastically different pressure-distance curves. So for comparison purposes--and that's what equivalencies mean to do--compare the unknown or test explosion or explosive to the known one of the same shape. In other words, compare apples to apples.

I overlay on to this figure the data (scaled to 1 lb) for the solid propellent test explosions. If I have made myself clear thus far, I'm sure you know to which curve I should compare the propellent data to get its TNT equivalence--to the cylindrical curve. The propellent data was for a rocket configuration of an L/D of about 5.

Now I can go through the arithmetic of calculating the equivalent weight of the propellent. I do it at several pressure levels and come up with Figure 3. Here we see two equivalent weight versus pressure curves--one for test data for a 60" diameter test rocket, the other for a 72" test rocket. Both curves indicate that at the lower pressures indeed the propellent has a bigger airblast kick than TNT. But above 5 to 7 psi, the propellent has an equivalent weight much less than TNT. I think that this variation of equivalent weight with pressure and the higher equivalent weight at low pressures is understandable in terms of the thermo chemistry of the rocket explosion. The propellent has a lower detonation velocity than TNT; hence, the initial pressures are lower. Also, the propellent has a larger after-burning contribution to airblast; hence, this late time phenomenon adds to the lower pressures and hence, give larger equivalences than TNT.

If all things were replicate in the experiments with the 60" and 72" rockets, there would be but one curve on this figure. But they weren't replicate situations; the 60" rocket did not achieve full detonation velocity--hence the lower output.

Okay--that's the way to get a self consistant, physically meaningful, unequivocal equivalent weight. What was done in the original report? The propellent data were compared to the data obtained from a hemispherical charge sitting on the ground! When this is done, you get a spectrum of equivalent weights as shown in Figure 4. The equivalent weight varies from about 1.2 to 2.3. So to play it "safe"--the report quotes an equivalence of 200+%. If I want a higher number,--play it safer--I could compare the propellent data to a true surface burst. I could do this and be wrong--just as wrong as when I compared it to a hemisphere.

I suppose if it were readily apparent as to what the basis of comparison is, things wouldn't be completely bad. But one has to dig in the report--and it's references--to determine this basis. And knowing this basis only gives you an inkling of the problem--not the solution. I suggest that if we always maintain the basic tenets of similitude--same charge shape, same confinement, same geometry of interest, between the standard and new explosion or explosive, we could skip stating the basis; we would just know it as good engineers and scientists.

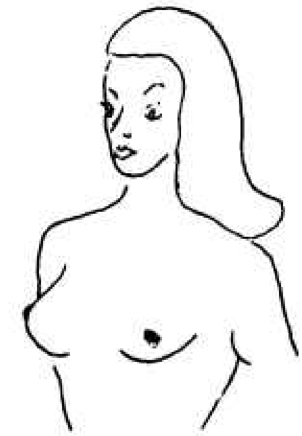
I didn't do a detailed analysis on the stacked explosive equivalent weight study I ran across. But I did determine that the basis of comparison for the cubically stacked munitions was

again a hemispherical charge. I know the answers are going to be wrong because I know that in close to the charge, at the distances of interest to magazine design, the pressure field around a cube is different from that around a hemisphere. In a line at right angles to the face of the cube, the pressures are going to be significantly higher than from an equivalent weight hemisphere. In line with the corners, the pressures again are going to be different than for a hemisphere. You just can't compare apples to turnips.

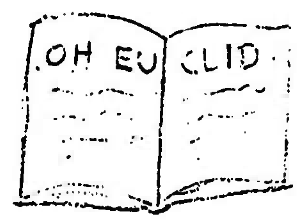
I think there are at least two reasons for the confusion. One--some people don't know better; perhaps we in the pure explosions field, the research field, haven't publicized our data sufficiently and addressed it to the user activities. We're too wrapped up in the pure physics of the problem. And second, really, there may not be enough data for all the odd ball geometries found in real life. We play around with simple geometric shapes--spheres and hemispheres on the ground, and spheres in free air--but many safety people never run into these geometries. So to get good, physically meaningful, unequivocal equivalent weight values, we should do more research on the basic shapes and conditions of interest to safety people--the stacking of munitions, the cased charge warheads, and the different L/D's of rocket interest. Then we will have a basis for comparison. And then, hopefully, we can observe the basic tenets of comparisons--as I said in my first figure, I say in my last--meaningful comparisons--equivalent weights--can be made only if we use the (1) same charge shapes (2) the same geometries of interest and (3) the same pressure ranges.

FOR EQUIVALENT WEIGHTS

(1) Same charge shape



(2) Same test geometry



(3) Same pressure range

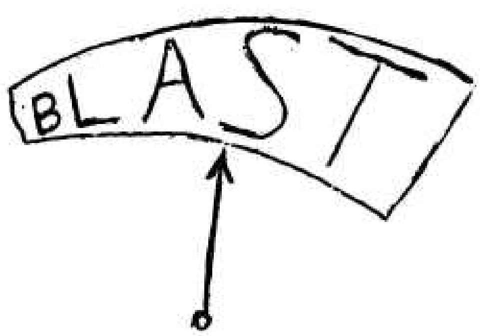
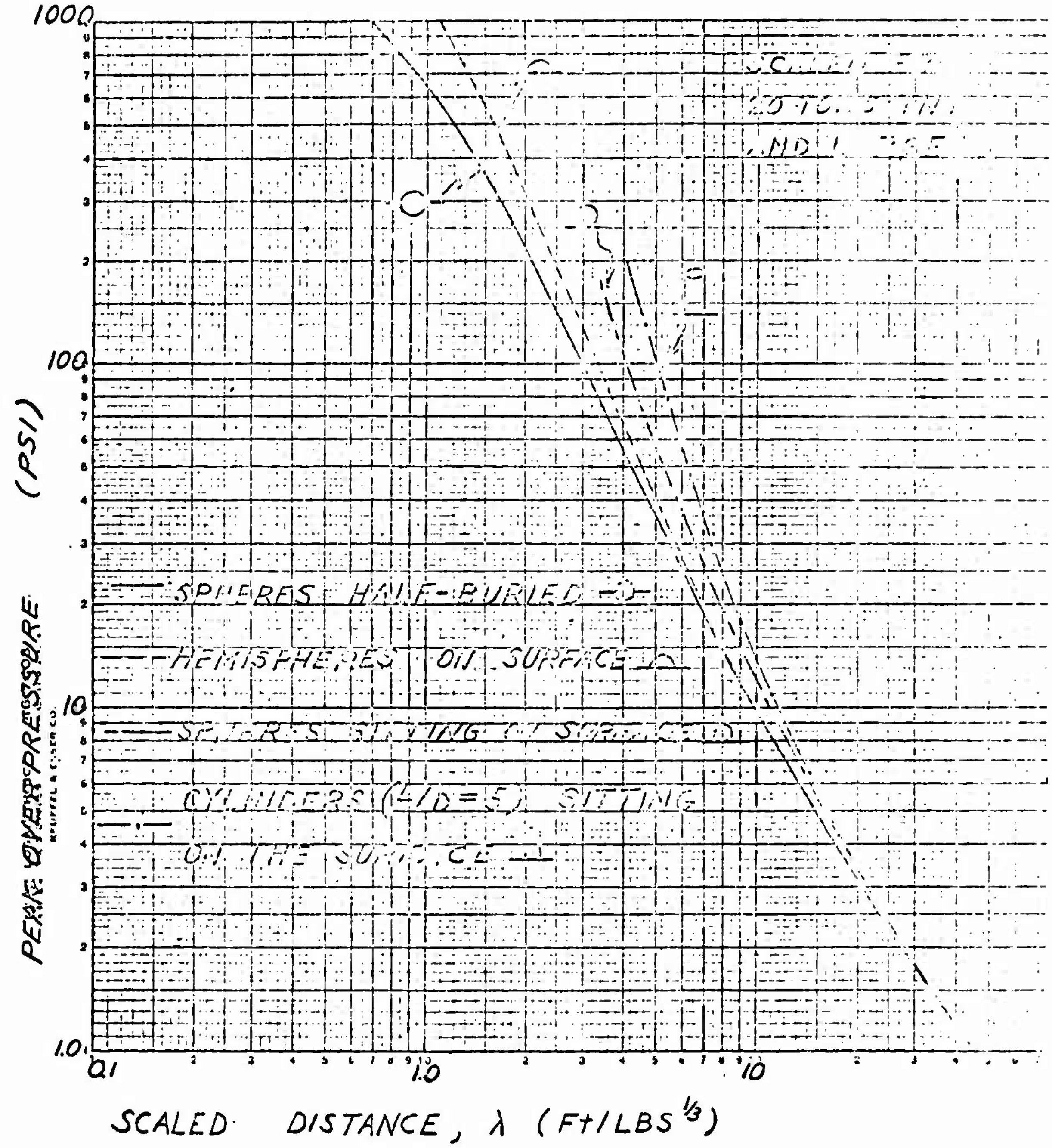


FIG. 2 PEAK OVERPRESSURE FROM TNT CHARGES ON THE SURFACE



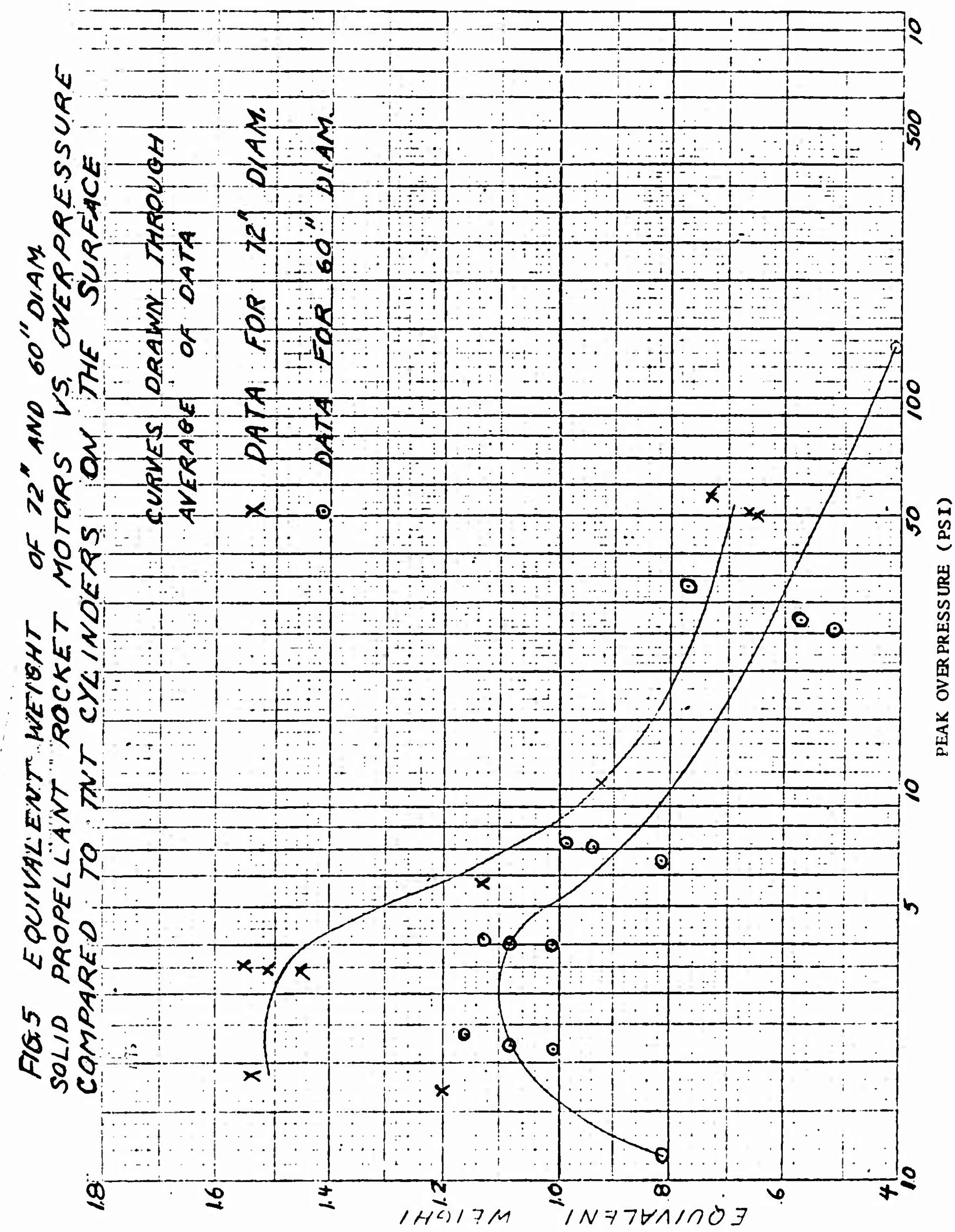
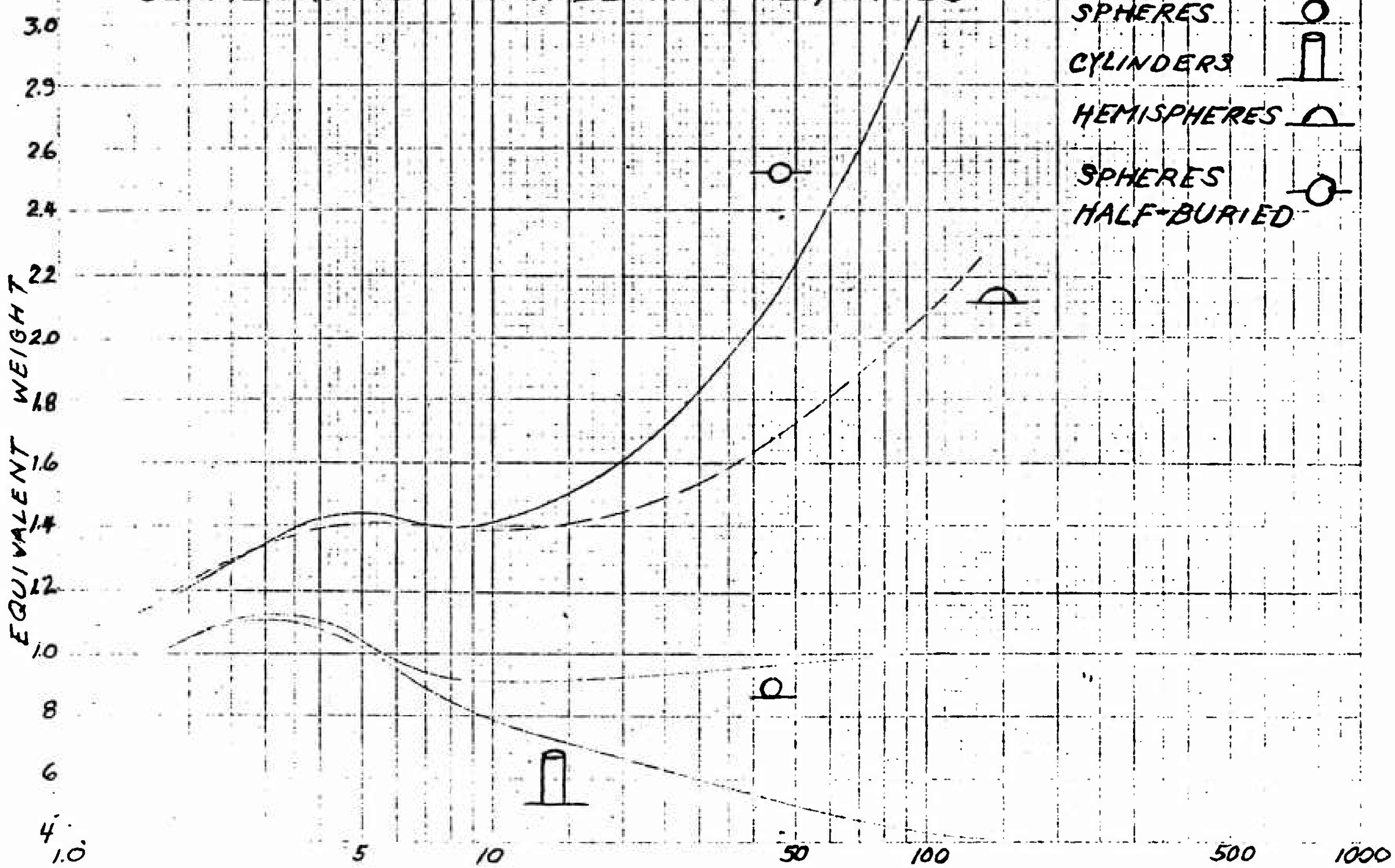


FIG.5 EQUIVALENT WEIGHT OF 72" AND 60" DIAM SOLID PROPELLANT ROCKET MOTORS VS. OVERPRESSURE COMPARED TO TNT CYLINDERS ON THE SURFACE

FIG. 6 EQUIVALENT WEIGHT VERSUS PRESSURE FOR 60" DIAM. SOLID PROPELLANT - ROCKET MOTORS COMPARED TO DIFFERENT GEOMETRICAL SHAPED TNT CHARGES



PEAK OVERPRESSURE (PSI)

AMMONIUM NITRATE/FUEL OIL, (AN/FO), A SAFER AIRBLAST SOURCE

By L. D. Sadwin
U. S. Naval Ordnance Laboratory

AN/FO is being developed as an airblast source for nuclear blast simulation. The results of recent blast measurements on AN/FO charges weighing up to 100 tons will be presented in this paper. These results indicate that the AN/FO blast performance closely approximates that of TNT. Thermal stability results will also be presented for the 20 and 100 ton hemispherical charges tested.

The safety advantages of AN/FO over the use of TNT and other explosives used for large explosions are numerous. The ease of handling factor becomes quite significant when large explosions are contemplated. AN/FO explosive placement operations take about one fourth of the time required for a comparable size, cast block, TNT charge. Bulk handling techniques developed by industry for AN/FO mixing and placement reduce the personnel requirement considerably. Fewer men are thus exposed to the explosive hazard. In addition, since the fuel oil is not mixed with the fertilizer grade ammonium nitrate until placement, the hazards during transport to the firing site are far less than for any other known explosive system.

This paper covers the applicable technical and safety aspects of the handling, thermal stability, sensitivity and airblast performance of large scale AN/FO charges.

Note by Moderator: As a result of attempting to make measurements in the high pressure range from AN/FO charges, NOL no longer gives a single number for the TNT equivalence of AN/FO. A curve of equivalent weight versus overpressure was presented and discussed.

ANALYSIS AND CORRELATION OF
UNDERWATER EXPLOSION DATA AT NOL

By:

Donald E. Phillips
Naval Ordnance Laboratory
Silver Spring, Maryland

ABSTRACT: The methods used in acquiring, analyzing, and correlating data from underwater explosion tests are discussed. These include preliminary tests of small (1-lb) charges of new compositions using diaphragm gages, and tests of larger charges using more elaborate instrumentation. Methods for computing equal weight and equal volume ratios, and for computing equivalent weights, are presented. The possible variation of these values with distance will be discussed, and methods of making estimates from limited data will also be given.

NOTE: Vugraphs were received too late to be processed for inclusion in these minutes.

1. INTRODUCTION

The assessment of the underwater performance or output of a new explosive composition is of utmost importance in determining its suitability for use in Navy weapons. Depending on its intended use, this assessment is made in various forms, such as equal weight or equal volume ratios, or expressed in terms of an equivalent weight of some standard high explosive, usually HBX-1 or Pentolite.

These various methods are often used with the results appearing only as a number (Explosive X is so much better than HBX-1). The manner in which this number is arrived at, however, is not well known, nor are its limitations. It is the purpose of this paper to summarize these various assessment procedures, to derive the necessary equations, and to show the possible dependence of such values on distance from the charge.

2. DETERMINATION OF RELATIVE PERFORMANCE USING 1-LB CHARGES

In the development of new explosive compositions, initial underwater tests are usually made with 1-lb charges, using diaphragm gages to determine their shock wave performance. Period and radius measurements are also made, from which relative bubble energies are determined.

(VUGRAPH 1) The diaphragm gage is essentially on an air-backed steel plate, 0.038 inches thick and about six inches

square. It is rigidly mounted and is permanently deformed by the action of the shock wave. Four gages are used on each test, and they are located on a ring about 42 inches (or ~ 33 charge radii) from the charge. The depth of deformation of a diaphragm gage has been related to the shock wave energy. Thus, together with the bubble measurements, estimates of both shock wave and bubble energies are obtained on this type of test.

As with all equivalencies which will be discussed in this paper, performance is determined relative to a standard fired as part of the same series. For 1-lb charge tests, the standard explosive used is Pentolite. (VUGRAPH 2). The diaphragm gage is calibrated by firing different weights of Pentolite and obtaining a plot of deformation as a function of charge weight. Using this plot, the deformation obtained with the experimental charge is converted to an equivalent weight of Pentolite. The relative performance then is expressed in terms of an equivalent weight ratio, or W_{Dd}:

$$W_{Dd} = \frac{\text{equiv. wt. of Pentolite}}{\text{actual charge wt}} \qquad (1)$$

Since relatively large boosters are often used, the value of W_{Dd} often must be corrected for the booster weight to obtain a realistic value for the experimental explosive.

Bubble energies are determined from measurements of the bubble pulse and maximum bubble radius. Bubble pulse measurements are obtained by use of a piezoelectric gage, while radii

are measured using a resistance probe developed at NOL. (VUGRAPH 3). Bubble energies relative to the Pentolite standards are then defined as:

$$\mathrm{RBE} = \left(\frac{K(x)}{K(s)}\right)^3 \tag{2}$$

$$\mathrm{RPBE} = \left(\frac{J(x)}{J(s)}\right)^3 \tag{3}$$

J and K are defined in reference (1). The x and s in parenthesis refer to the experimental and standard explosive, respectively.

The latter bubble energy (RPBE) is a recent addition to our testing procedure. It has been included because NOL now believes this comparison represents a better evaluation of bubble energy than does RBE, as it reflects the available energy which is capable of doing mechanical work.

The evaluation of explosives using 1-lb charges has both its advantages and limitations. These are (VUGRAPH 4):

Advantages:

1. High firing rate;
2. Rapid data analysis and access to results;
3. Relatively low cost (because of simple instrumentation, rapid firing rate).

Limitations:

1. Only a single shock wave parameter measured;
2. Evaluation made at only one range;
3. Comparison by weight only;
4. Possible detonation problems with small charges;
5. Relatively large boosters often required.

One-lb programs thus serve as a valuable screening method for new explosives. Small charge programs are also useful for optimizing the underwater performance of a chemical matrix for studies of chemical processes involved with explosives such as boostering and density effects, and for studies of various enhancement techniques such as separated charges. To fully evaluate the performance of an explosive for underwater use, however, it is necessary to fire large charges and obtain detailed measurements of the shock wave.

3. EVALUATION OF PERFORMANCE USING LARGE CHARGES

Once an explosive shows promise in 1-lb programs, larger charges are fired and more detailed shock wave measurements are obtained. Charge weights may vary from 10 lb up to actual warhead size, perhaps as great as 1000 lb. For these tests, piezoelectric gages are used to obtain pressure histories at several distances from the explosive charge. Bubble measurements are the same as those made for the 1-lb charges. A typical charge-gage rig is shown in VUGRAPH 5. Recording is accomplished using either oscilloscopes, where the trace is recorded photographically, or magnetic tape recorders. Generally gages are located at reduced distances ($W^{1/3}/R$) ranging from 0.72 to 0.072 $lb^{1/3}/ft$. This corresponds to pressure levels of from about 16,000 psi to about 1200 psi.

3.1 Shock Wave Parameters

Before discussing the determination of the various equivalency factors, let us first review briefly the parameters of interest.

The shock wave emitted by an underwater explosion consists of a sharp (essentially instantaneous) rise in pressure, followed by an initially exponential decay. The shock wave parameters, than are: peak pressure, time constant (or decay time of the shock front), impulse (integral of pressure-time), and energy (integral of pressure squared-time).

(VUGRAPH 6) Based on several years of gathering experimental data, it has been found that these parameters can conveniently be expressed as functions of weight and distance by means of similitude equations. The general forms of these equations are:

$$\text{Peak Pressure:} \quad P_m = C_P \left(\frac{W^{1/3}}{R}\right)^{\alpha_P} \tag{4}$$

$$\text{Time Constant:} \quad \theta = C_\theta \, W^{1/3} \left(\frac{W^{1/3}}{R}\right)^{\alpha_\theta} \tag{5}$$

$$\text{Energy Flux Density:} \quad E = C_E \, W^{1/3} \left(\frac{W^{1/3}}{R}\right)^{\alpha_E} \tag{6}$$

$$\text{Impulse:} \quad I = C_I \, W^{1/3} \left(\frac{W^{1/3}}{R}\right)^{\alpha_I} \tag{7}$$

where:

P_m = peak pressure, psi

θ = time constant, msec

E = energy flux density, in-lb/in^2

I = impulse, psi-sec

W = charge weight, lb

R = distance or standoff from the charge, ft

C = coefficient characteristic of a particular explosive

α = exponent of the similitude equation, also in general characteristic of a given explosive

(subscripts P, θ, E, I refer to the appropriate parameter).

For a given experimental program, similitude equations are obtained using the digital computer by applying least squares fits to the experimental data. Because the data sample is small (perhaps only four shots of each explosive having been fired), these are not the similitude equations for a given explosive and not in themselves intended for use in describing the free water shock wave behavior of that explosive. Rather, they form the basis from which the various comparisons are subsequently made. Generally, the fits are made in reduced form of the similitude equations using values of P_m, $\theta/W^{1/3}$, $I/W^{1/3}$, and $E/W^{1/3}$ to facilitate comparisons where weights are unequal, and for future use in developing final similitude equations for a composition utilizing data from several charge weights.

3.2 Correlation of Data

(VUGRAPH 7) Once the pressure-time records have been analyzed for the shock wave parameters and the similitude equations obtained, the manner in which these parameters are used to compare the output of the new explosive relative to the standard depends on the intended use of the composition. It should be noted that these comparisons are made relative to data from standard charges fired in the same series, and not from the absolute similitude equations available for the standard, such as those in reference (2). The most generally used comparisons are (VUGRAPH 8):

(1) Equal Weight Ratio: The ratio of the outputs with respect to a particular parameter (peak pressure, time constant, impulse, or energy flux density) for equal weights of two explosives at the same distance. (This is of interest in the design of weight-limited weapons.)

(2) Equal Volume Ratio: The ratio of outputs with respect to a particular parameter for equal volumes of two explosives as measured at the same distance. (This is of interest in the design of volume-limited weapons.)

(3) Equivalent Weight Ratio: The ratio of weights of two explosives required to produce the same magnitude of a particular parameter at the same distance.

(4) Equivalent Volume Ratio: This has only recently become of interest and will not be discussed today. Its definition follows from the equivalent weight ratio.

In order to keep the paper brief, we will derive these ratios only for peak pressure. For the other parameters, the approach is the same, although the final forms of the equations may be somewhat different. For those interested in greater detail, they are referred to TR 69-192 (reference 3) for this information.

3.3 Computation of Equal Weight Ratios

(VUGRAPH 9). Equal weight ratios describe the change of a given shock wave parameter of a new explosive compared with the standard explosive, for charges having the same weight. It is the ratio, for example, of the peak pressure measured from an experimental charge to that measured from the standard,

both at the same range and of the same weight. If D_{Wd} refers to the equal weight ratio, then

$$D_{Wd(P)} = \frac{P(x)}{P(s)} \tag{8}$$

for:

$$W(x) = W(s) = W \tag{9}$$

$$R(x) = R(s) = R \tag{10}$$

If the exponents of the similitude equations for the two explosives are not the same, no single value of equal weight ratio can be computed, as the ratio is then a function of weight and distance. This can be shown by substituting the righ hand sides of the similitude equations for the experimental and standard explosives in Equation (8). For peak pressure:

$$P_m(x) = C_{P(x)} \left(\frac{W(x)^{1/3}}{R(x)}\right)^{\alpha_{P(x)}}$$

$$P_m(s) = C_{P(s)} \left(\frac{W(s)^{1/3}}{R(s)}\right)^{\alpha_{P(s)}}$$

(**VUGRAPH** 10). Using Equations (9) and (10) for weight and distance and the above two equations, the following relationship for the equal weight ratio is obtained.

$$D_{Wd(P)} = \frac{P_m(x)}{P_m(s)} = \frac{C_{P(x)}}{C_{P(s)}} \cdot W^{(\alpha_{P(x)} - \alpha_{P(s)})/3} . R^{\alpha_{P(s)} - \alpha_{P(x)}} \tag{11}$$

Equation (11) shows a dependence of the equal weight ratio on both charge weight and distance. However, as was mentioned in Section 2, for different charge weights, measurements are

made at the same reduced distance, not at the same distance. Returning to equations (4) and (8), it can be seen that, at the same reduced distance, the magnitudes for each explosive, and thus the equal weight ratio, will be the same regardless of charge weight. Thus, from a practical standpoint, the important variation in the equal weight ratio is with distance.

If the exponents of the two similitude equations are equal ($\alpha_{P(s)} = \alpha_{P(s)} = \alpha_P$), then equation (11) reduces to:

$$D_{Wd(P)} = \frac{P(x)}{P(s)} = \frac{C_{P(x)}}{C_{P(s)}} \qquad (12)$$

Likewise, the equal weight ratios for the other parameters can be expressed as ratios of the coefficients of the similitude equations, if the exponents of the two similitude equations are the same.

3.4 Computation of Equal Volume Ratios

(VUGRAPH 11). The equal volume ratio, as the name implies, refers to the change in output observed in a particular parameter from an experimental explosive relative to a standard explosive, both charges having the same volume. Such a comparison has been of considerable interest in recent years as many of the new weapons systems are volume-limited in the amount of explosive they can carry. Thus, letting D_{Vd} indicate the equal volume ratio,

$$D_{Vd(P)} = \frac{P(x)}{P(s)} \qquad (13)$$

where:

$V(x) = V(s)$ (= V, volume, ft^3)

$R(x) = R(s) = R$

The similitude equation can be expressed as a function of volume by replacing W with ρV. Thus

$$P(x) = C_{P(x)} \cdot \rho(x)^{\alpha_{P(x)}/3} \cdot \left(\frac{W(x)^{1/3}}{R}\right)^{\alpha_{P(x)}}$$

where:

ρ = experimental density, lb/ft^3

(VUGRAPH 12) For non-equal exponents, the following equation is obtained:

$$D_{Vd(P)} = \frac{C_{P(x)}}{C_{P(s)}} \cdot \rho(x)^{\alpha_{P(x)}/3} \cdot \rho(s)^{-\alpha_{P(s)}/3} \cdot V^{(\alpha_{P(x)}-\alpha_{P(s)})/3}$$

$$\cdot R^{\alpha_{P(s)}-\alpha_{P(x)}} \qquad (14)$$

If the exponents are equal, this reduces to:

$$D_{Vd(P)} = \frac{C_{P(x)}}{C_{P(s)}} \cdot \left(\frac{\rho(x)}{\rho(s)}\right)^{\alpha_P/3} \qquad (15)$$

It is interesting to note the relationship between the equal weight and equal volume ratios if the exponents are the same. Comparing equation (12) and (15), it can be seen that the equal volume ratio is equal to the equal weight ratio multiplied by the ratio of densities raised to an exponent. Such a relationship is of importance if it is necessary to compute one ratio from the other.

3.5 <u>Computation of Equivalent Weight</u>

(VUGRAPH 13) It is often useful to the engineer or designer to have the comparison made in terms of the weight required to produce the same magnitude in a particular parameter. This is referred to as the equivalent weight, which for a given shock wave parameter expresses the number of pounds of a standard

explosive required to give the same magnitude of that parameter at the same range as does a given weight of experimental explosive.

Letting W_{Dd} refer to the equivalent weight ratio, then

$$W_{Dd(P)} = \frac{W(s)}{W(x)} \tag{16}$$

for

$$P_m(s) = P_m(x) = P_m \tag{17}$$

$$R(s) = R(x) = R \tag{18}$$

(VUGRAPH 14). Inserting the right sides of the similitude equations for $P_m(s)$ and $P_m(x)$ in equation (17) and solving for $W(s)$, the following relationship is obtained:

$$W(s) = \frac{C_{P(x)}}{C_{P(s)}}^{3/\alpha_{P(s)}} \cdot R^{3\left(1 - \frac{\alpha_{P(x)}}{\alpha_{P(s)}}\right)} \cdot W(x)^{\left(\frac{\alpha_{P(x)}}{\alpha_{P(s)}}\right)} \tag{19}$$

For equal exponents, equation (19) reduces to:

$$W(s) = \left(\frac{C_{P(x)}}{C_{P(s)}}\right)^{3/\alpha_P} \cdot W(x) \tag{20}$$

The equivalent weight ratio, then is simply the equal weight ratio raised to an exponent, if the exponents of the similitude equations are the same.

4. ESTIMATES OF VARIABILITY

We have attempted in Section 3 to define the various comparison methods and to show that, if non-equal exponents exist between the similitude equations for the two explosives, these ratios will vary with distance. The engineer or weapons designer, however, is not interested in such complex relationships. He needs a single value which tells him how much better one explosive is than another. An average value for each parameter, obtained over

the range of distances for which measurements were obtained, appears to best answer his needs, except possibly in rare design problems where the designer is trying to optimize a system for a particular pressure or distance level. In such instances the appropriate values should be used instead of the average over the range of measurements. It is important in using an average to realize its limitations, a precaution that is often neglected or misunderstood.

To see how much variability might occur in such an average, let us consider the effect of a five percent difference in exponent for the two similitude equations for each parameter. This seems to be a reasonable estimate as differences of this magnitude have been observed in experimental programs. It may possibly be low for the time constant, where exponents from 0.18 to 0.29 have been observed (a difference of 45 percent, reference (2).

The computations were made using the similitude equations for HBX-1 as given in reference (2) for the standard, and increasing these exponents by five percent for the experimental explosive. The exponents used then are:

$$\alpha_{P(s)} = 1.15 \qquad \alpha_{P(x)} = 1.21$$
$$\alpha_{\theta(s)} = -0.29 \qquad \alpha_{\theta(x)} = -0.305$$
$$\alpha_{I(s)} = 0.85 \qquad \alpha_{I(x)} = 0.91$$
$$\alpha_{E(s)} = 2.00 \qquad \alpha_{E(x)} = 2.10$$
$$\rho(s) = 107 \text{ lb/ft}^3 \qquad \rho(x) = 118 \text{ lb/ft}^3$$

VUGRAPH 15 shows the percentage change in the various ratios over the range of reduced distances discussed in Section 2. Note that both peak pressure and energy flux density show the greatest variation. What this table says, for instance, is that based on peak pressure, the equivalent weight ratio will show a difference of 29 percent between that needed to produce the required magnitude at the position where the curves are matched and that needed at another position where the exponents have caused the curves to diverge, for the same weight of experimental explosive.

The variation shown in this Vugraph for the equal volume ratio is somewhat misleading in that, as can be seen in equations (14) and (15), the change in the equal volume ratio is dependent on densities as well as distance. For the particular example chosen, the effect of density tended to cancel the effect of distance, so that somewhat smaller variations were obtained. That there is a combined effect, however, should be kept in mind.

5. SUMMARY

We have attempted to show, at least briefly, how new explosives for possible underwater use are evaluated at NOL. Data collection, analysis, and correlation have been discussed. It has been shown that the various methods of comparing the free water output of new compositions, while useful, must be applied with caution, as it is likely that the correlation varies

with distance. While it is helpful to give the engineer or weapons designer a single number with which to work, that this number may vary by as much as 30 percent (depending on the range of interest) has, in the past, not been fully appreciated.

REFERENCES

1. Cole, R. H.; "Underwater Explosions"; Princeton University Press; 1948; Unclassified.

2. Thiel, M. A.; "Revised Simulitude Equations for the Underwater Shock Wave Performance of Pentolite and HBX-1"; NAVSEPS Report 7380; 1 Feb 1961; Naval Ordnance Laboratory; Unclassified.

3. Phillips, D. E.; "Analysis and Correlation of Underwater Explosion Data at NOL";NOLTR 69-192; 5 Dec 1969; Naval Ordnance Laboratory; Unclassified.

EQUIVALENT WEIGHTS OF EXPLOSIVE FILL CANDIDATES

Charles Kingery
Ballistic Research Laboratories
USA Aberdeen Research and Development Center

Peak shock overpressure and impulse were measured from several explosive fill candidates. The methodology used and unclassified results will be presented.

The results confirm the principle that equivalent weight is not a unique number, but must be specified over a pressure range. In spite of this, relative ranking of explosive fill candidates can be determined unambiguously. Measurement situations peculiar to munitions were also briefly described.

COMPARISON OF TNT WITH A COLD CASTABLE MIXED EXPLOSIVE

John H. Keefer
Ballistic Research Laboratories
USA Aberdeen Research and Development Center, Md.

The application for the cold castable mixed explosive that I am going to consider today is for nuclear simulation testing. During the past six years, considering only two test sites, over six million pounds of TNT have been used for nuclear simulation testing. Casting of TNT for large block built charges must be done under controlled laboratory conditions and thus, is time consuming and expensive. A long lead time is required in the preparation for a large scale test. Even though great care has been taken in the casting and building of these large charges, blast anomalies have occurred in the form of luminous jets eminating from the charge. These luminous jets caused non-radial flow and thus, can degrade the results of target response studies.

The major objective of this program was to find an explosive that would have the same air blast characteristics as TNT, and at the same time have the following advantages:

a. Field castable and self-supporting after forms are removed.

b. A more homogeneous charge with less fireball and shock wave anomalies.

c. Less expensive and available in large quantities.

In trying to find an explosive with the advantages just mentioned, we contacted several large explosive manufacturers and found them all very helpful in trying to meet our requirements. All of the commercial companies contacted have explosives that are field mixable. Most of these explosives are in slurry form and have been developed for mining applications. Our requirements that the explosive be self-supporting and duplicate the airblast parameters of TNT were not met by most of the commercially available explosives. One of the companies had produced an ammonia nitrate explosive that was castable and, at the time of our inquiry the company had given a contract to evaluate this new explosive and their findings showed that this new explosive was essentially free of fireball anomalies and had a compressive strength of over 200 psi. After receiving the results of this independent study, the Ballistic Research Laboratories (BRL) purchased two, 1000 pound spheres of this new explosive and had it shipped to the Defence

Research Establishment-Suffield (DRES), Alberta, Canada for testing. The testing was included in a height-of-burst study that was currently being carried out jointly by DRES and BRL. This height-of-burst program included ten, 1000 pound TNT spherical charges detonated at eight different heights of burst.

The two new explosive 1000 pound charges were detonated at a height of 65 feet above the surface, at a height the same as one of the TNT charges. By detonating it at this height, both free air and free field air blast pressure parameters were obtained. The free field pressure-time data, recorded by Bytrex gages mounted in the surface, are shown in Figure 1 and compared with TNT in Figure 3. A comparison between the free air pressure-time data is shown in Figure 2 and compared with TNT in Figure 4. This new explosive shows excellent repeatability and agreement with TNT.

The arrival time data from the new explosive and TNT are essentially the same as shown in Figure 5. The overpressure comparison as shown in Figure 6, shows good agreement at the higher pressure levels with slightly higher pressures being recorded in the low pressure regions. The positive phase duration, even though difficult to read, shows good agreement in Figure 7. Overpressure impulse is probably the most significant air blast parameter for target analysis and it shows excellent agreement at all distances (Figure 8).

In conclusion, I think you will agree the explosive equivalent weight for the cold castable explosive when compared with TNT, is one and the overall objectives of this program were achieved.

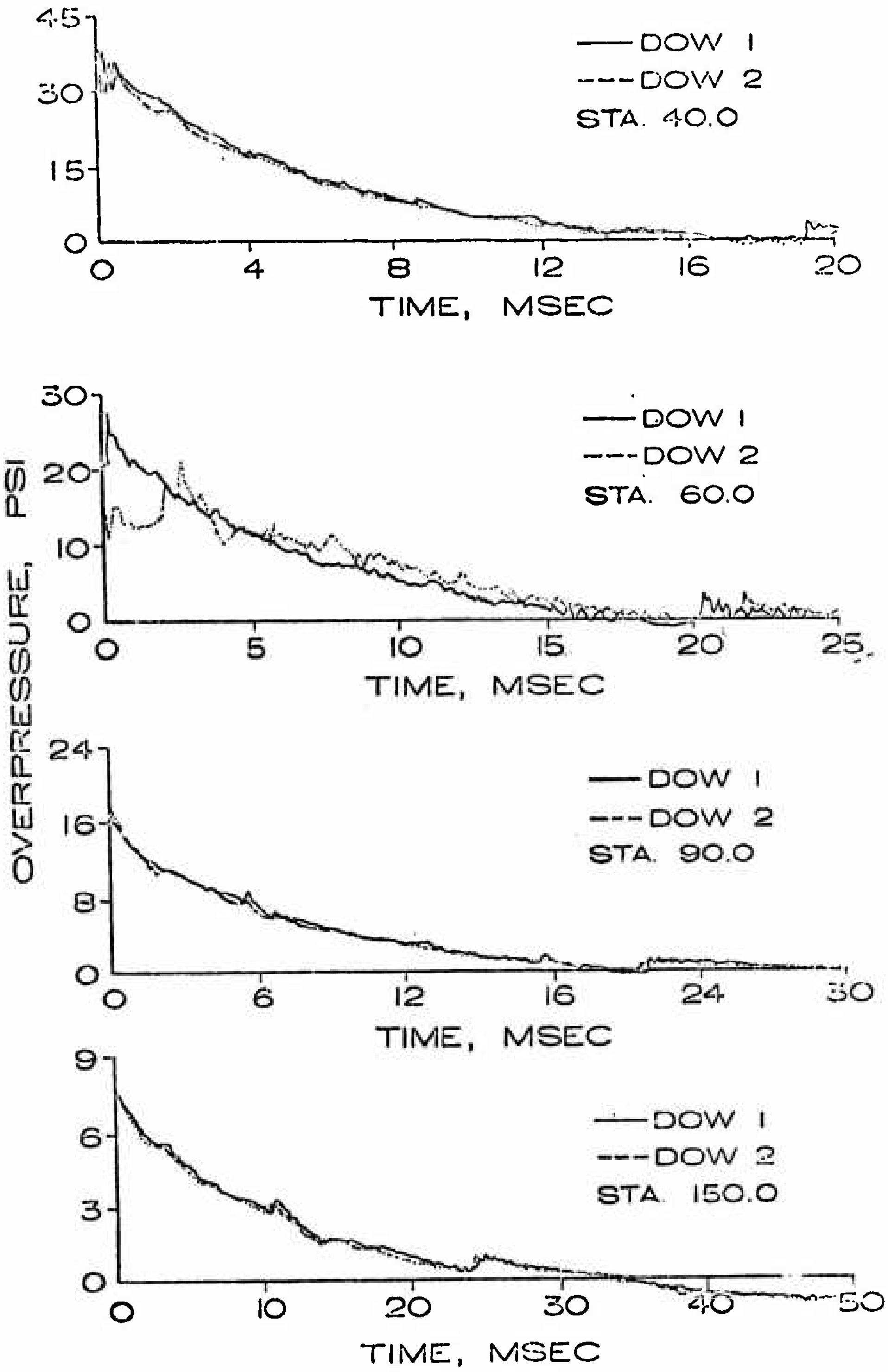


FIGURE 1. Comparison of Free Field Overpressure-time Records from a New Cold Castable Explosive

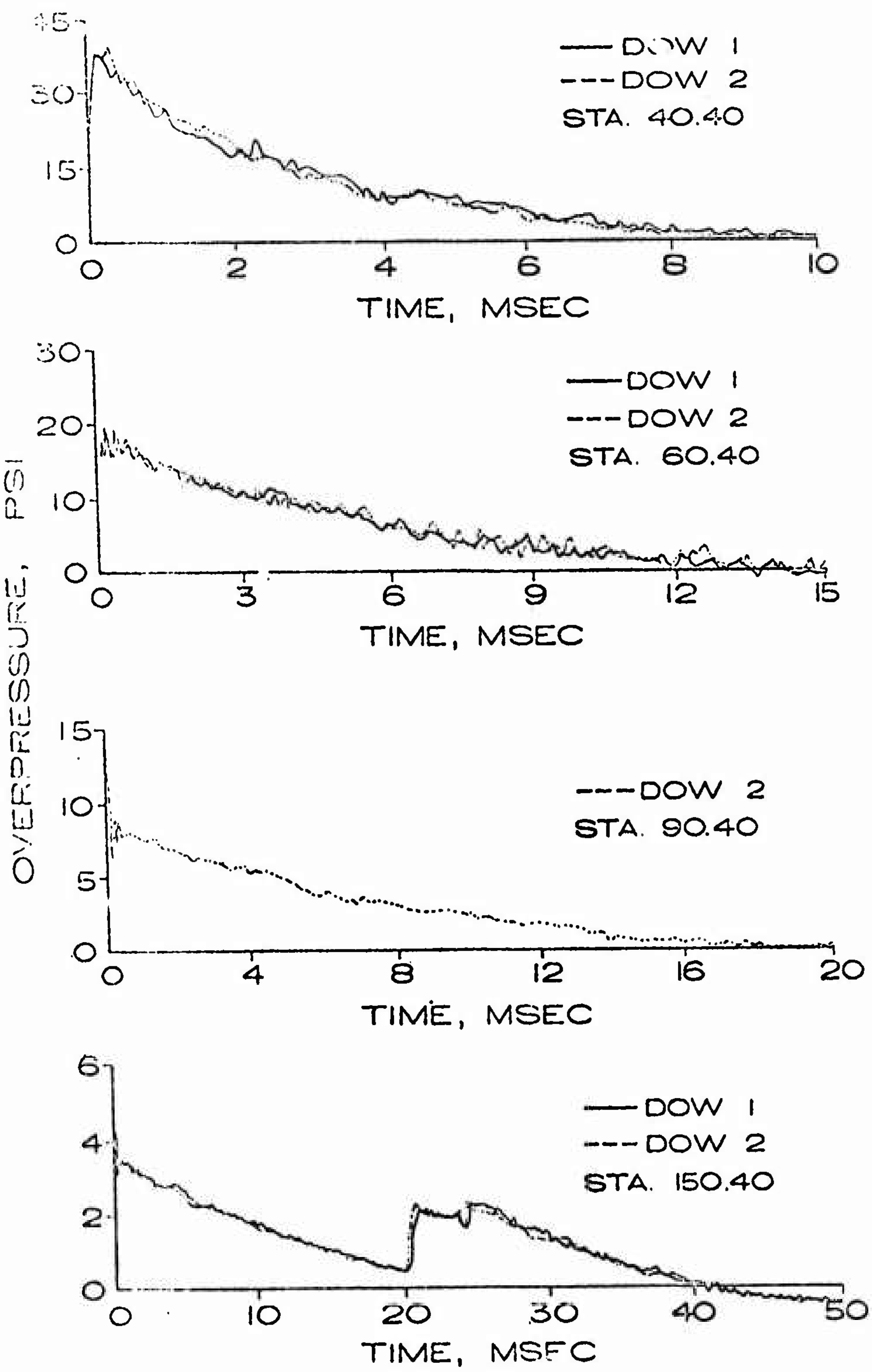


FIGURE 2. Comparison of Free Air Overpressure-time Records from a New Cold Castable Explosive

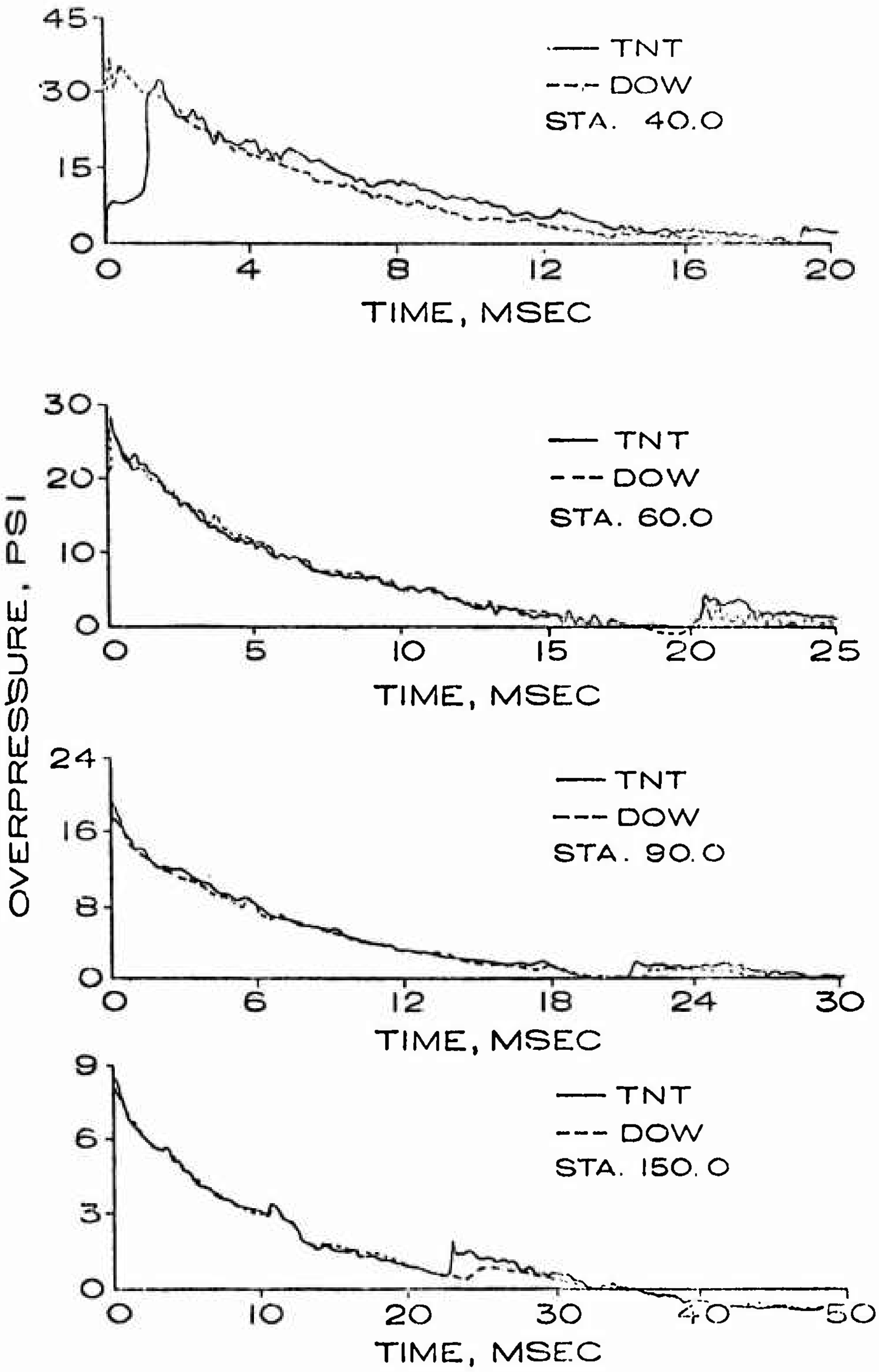


FIGURE 3. Comparison of Free Field Overpressure-time Records from a Cold Castable Explosive vs TNT

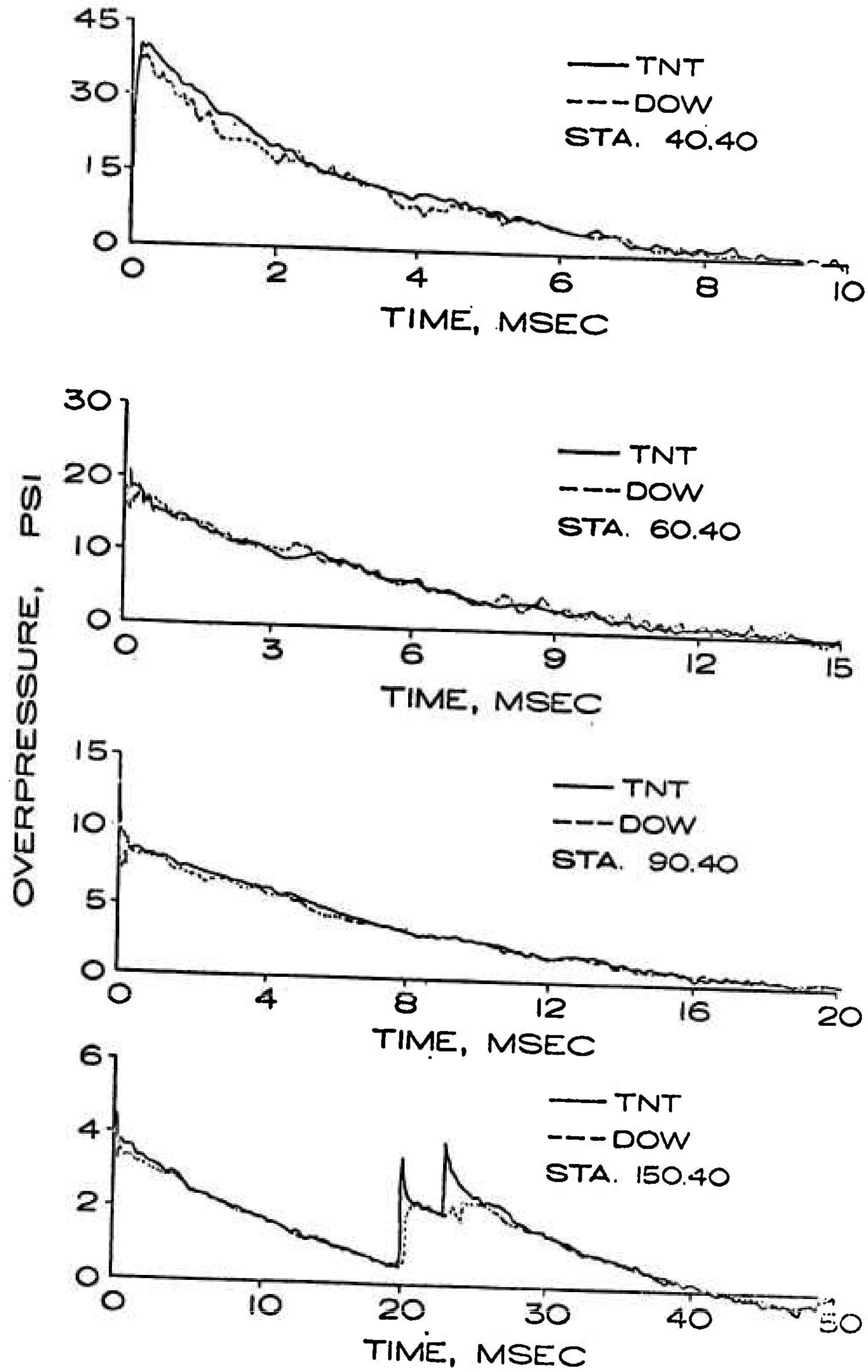


FIGURE 4. Comparison of Free Air Overpressure-time Records from a Cold Castable Explosive vs TNT

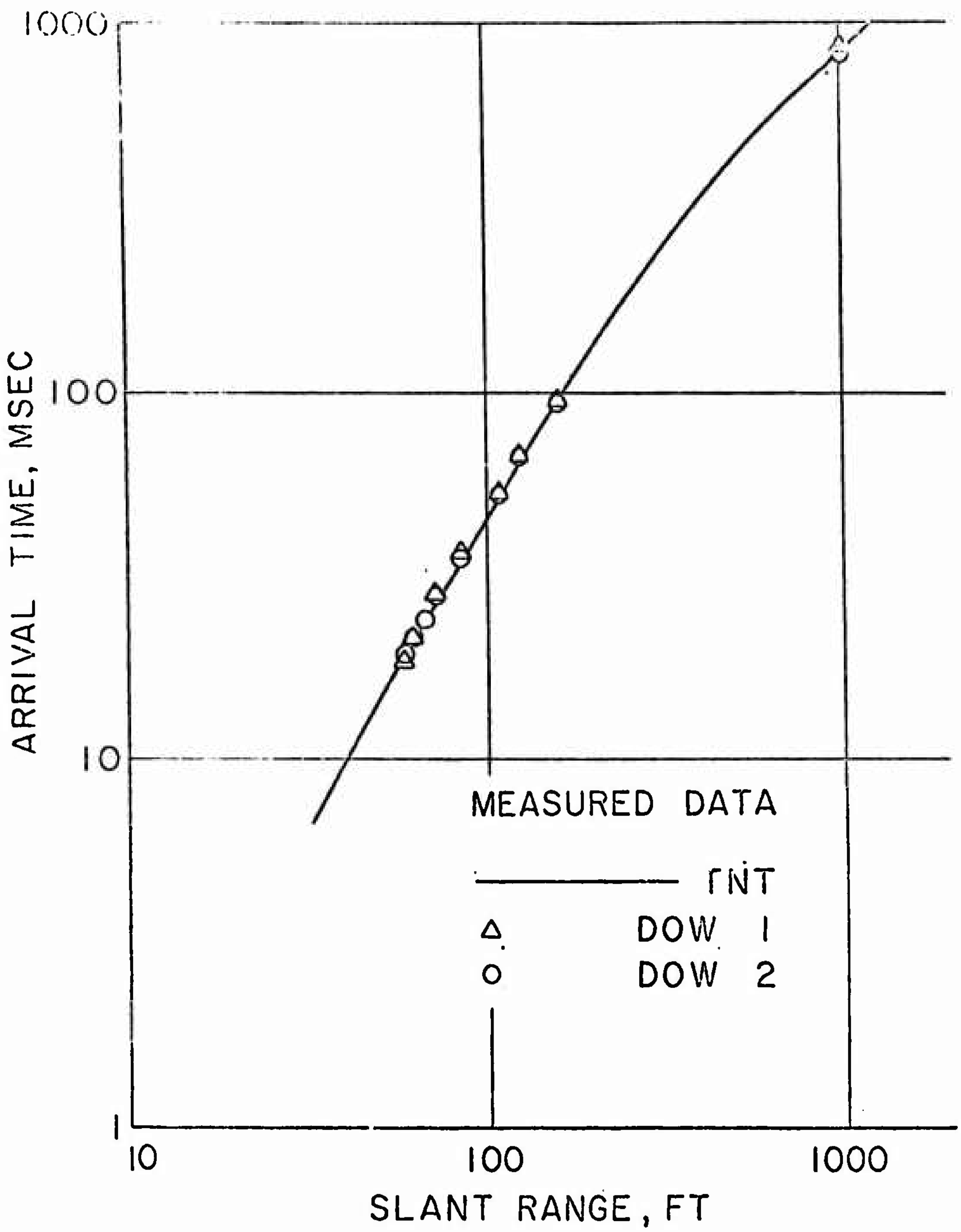


FIGURE 5. Shock Wave Arrival Time Comparison for a Cold Castable Explosive vs TNT

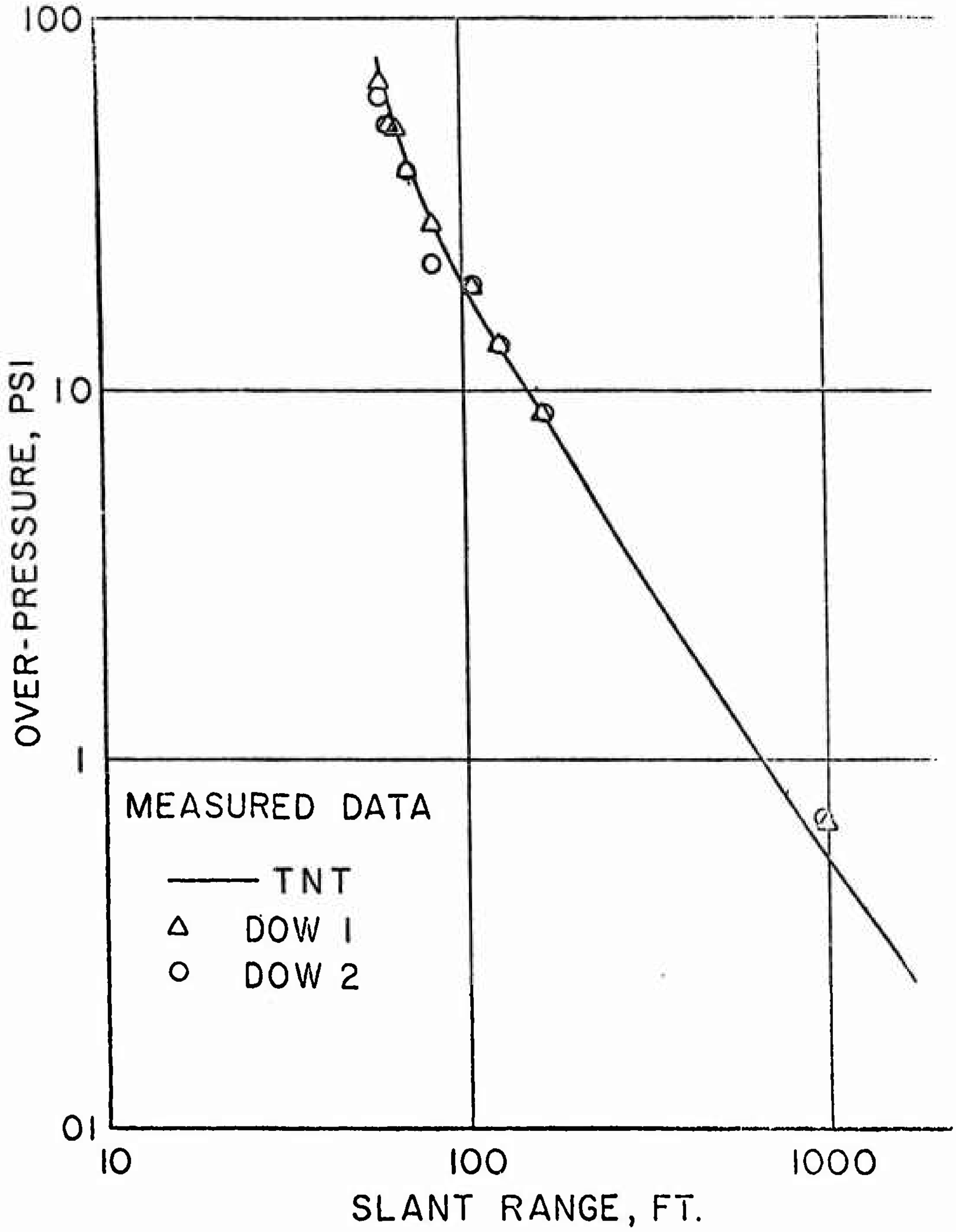


FIGURE 6. Maximum Overpressure Comparison for a Cold Castable Explosive vs TNT

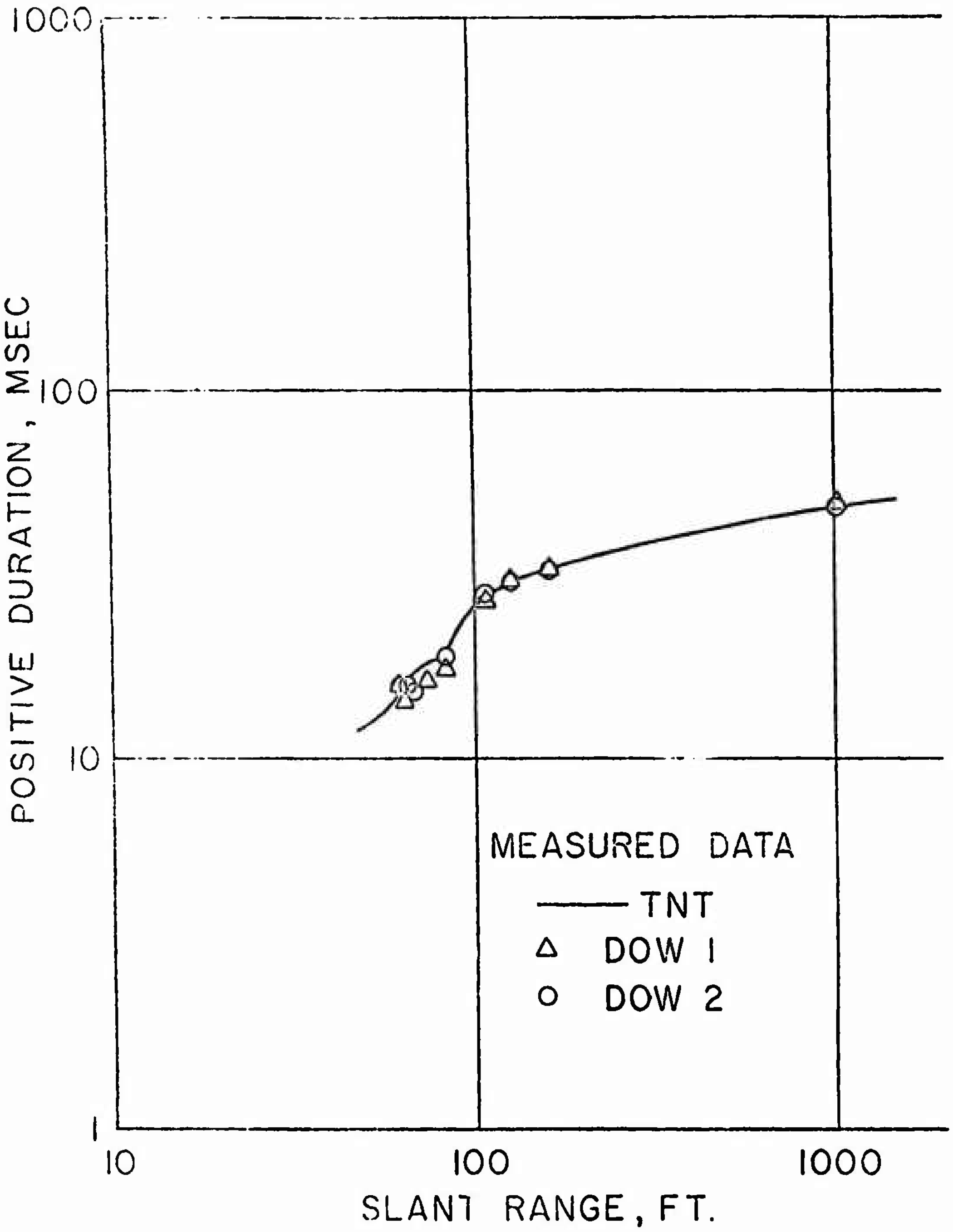


FIGURE 7. Positive Phase Duration Comparison for a Cold Castable Explosive vs TNT

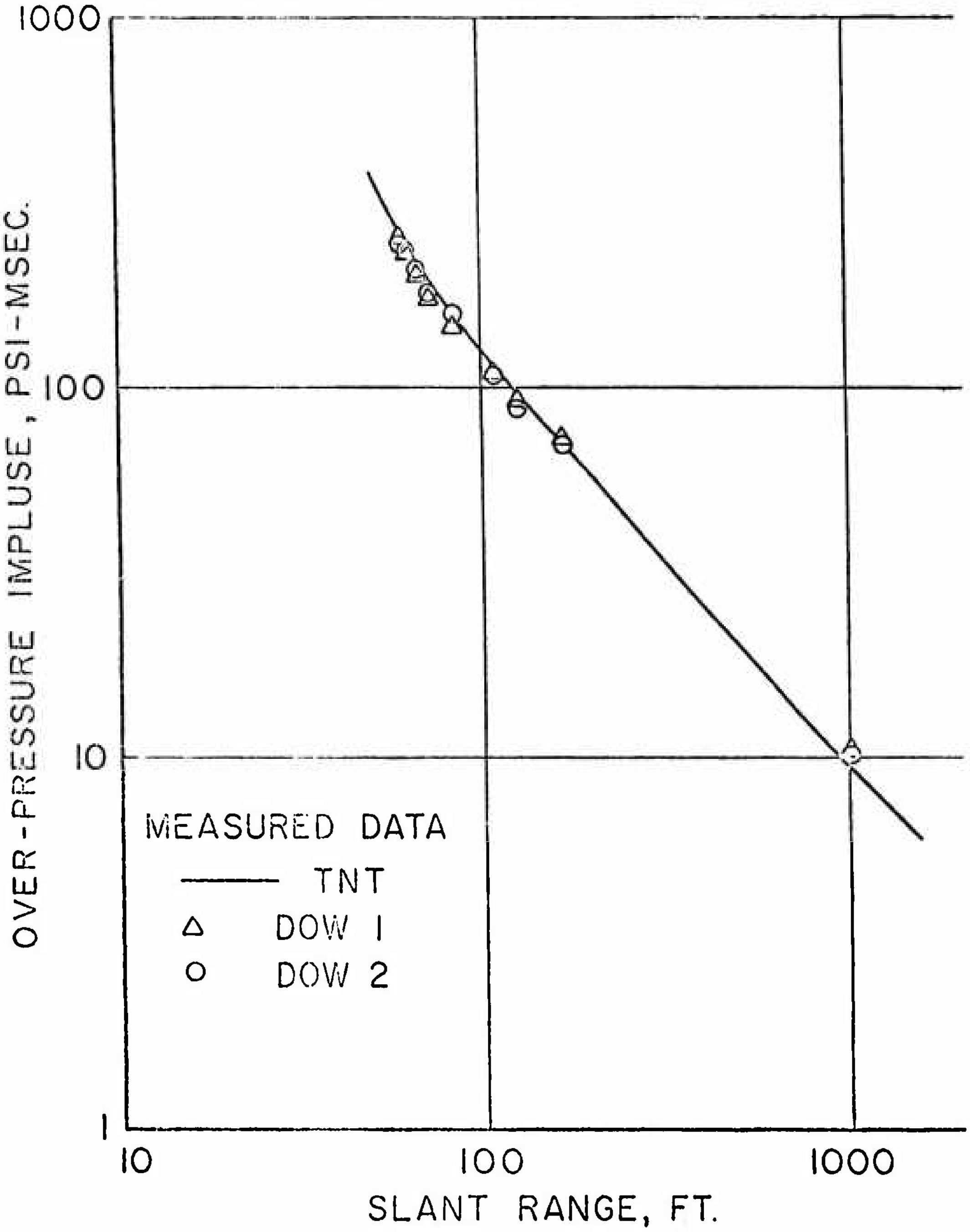


FIGURE 8. Overpressure Impulse Comparison for a Cold Castable Explosive vs TNT

AIR BLAST FROM 155mm STACK SEPARATION TESTS

Charles Kingery
Ballistic Research Laboratories
USA Aberdeen Research and Development Center, Md.

Objectives:

- Validate safe separation distances for stacked high explosive shell munition
- Determine explosive yield of a single stack configuration based on a standard explosive
- Determine difference in explosive yield between a single and triple stack configuration

Procedure Phase 1:

- Document the blast parameters from 1000, 155mm HE M101 shells stacked in a field configuration and detonated at the geometric center
- Install Overpressure vs Time instrumentation at Distances of 1010, 1380, 1800, and 2200 feet from ground zero

Procedure Phase 2

- Document the blast parameters from 3000, 155mm HE M101 shells in a three stack field configuration and detonated at the geometric center
- Record Overpressures vs Time at the same ground ranges established for phase 1

Results

- Compare blast parameters measured on single stack configuration with a standard (TNT hemisphere)
- Compare blast parameters measured on triple stack configuration with a standard (TNT hemisphere)

Conclusions:

- No significant difference in peak overpressure or impulse between single and triple stack
- Donor stack detonated high order on both shots
- Acceptor stacks on shot two did not detonate
- Significant differences in peak overpressure and impulse recorded along the base, side, and nose line

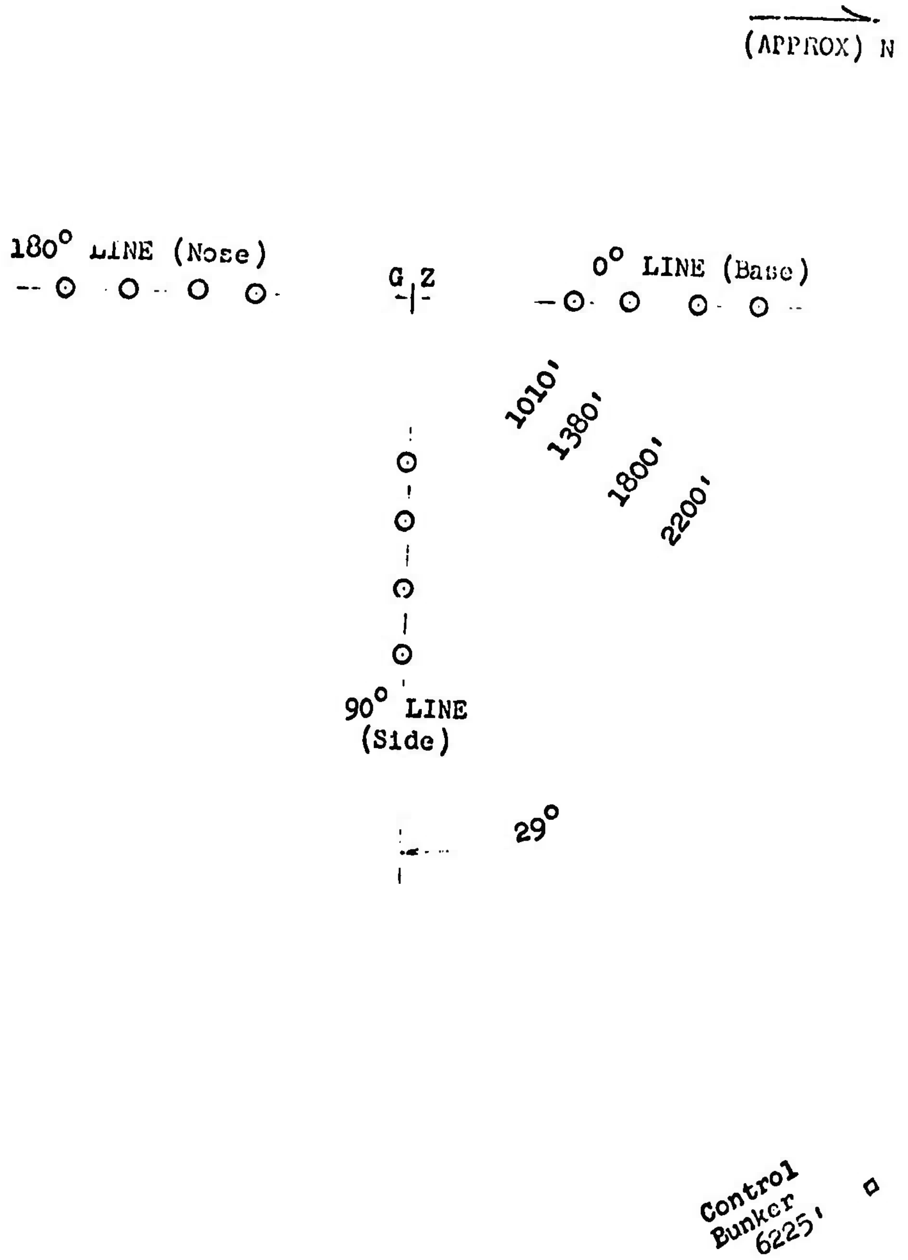
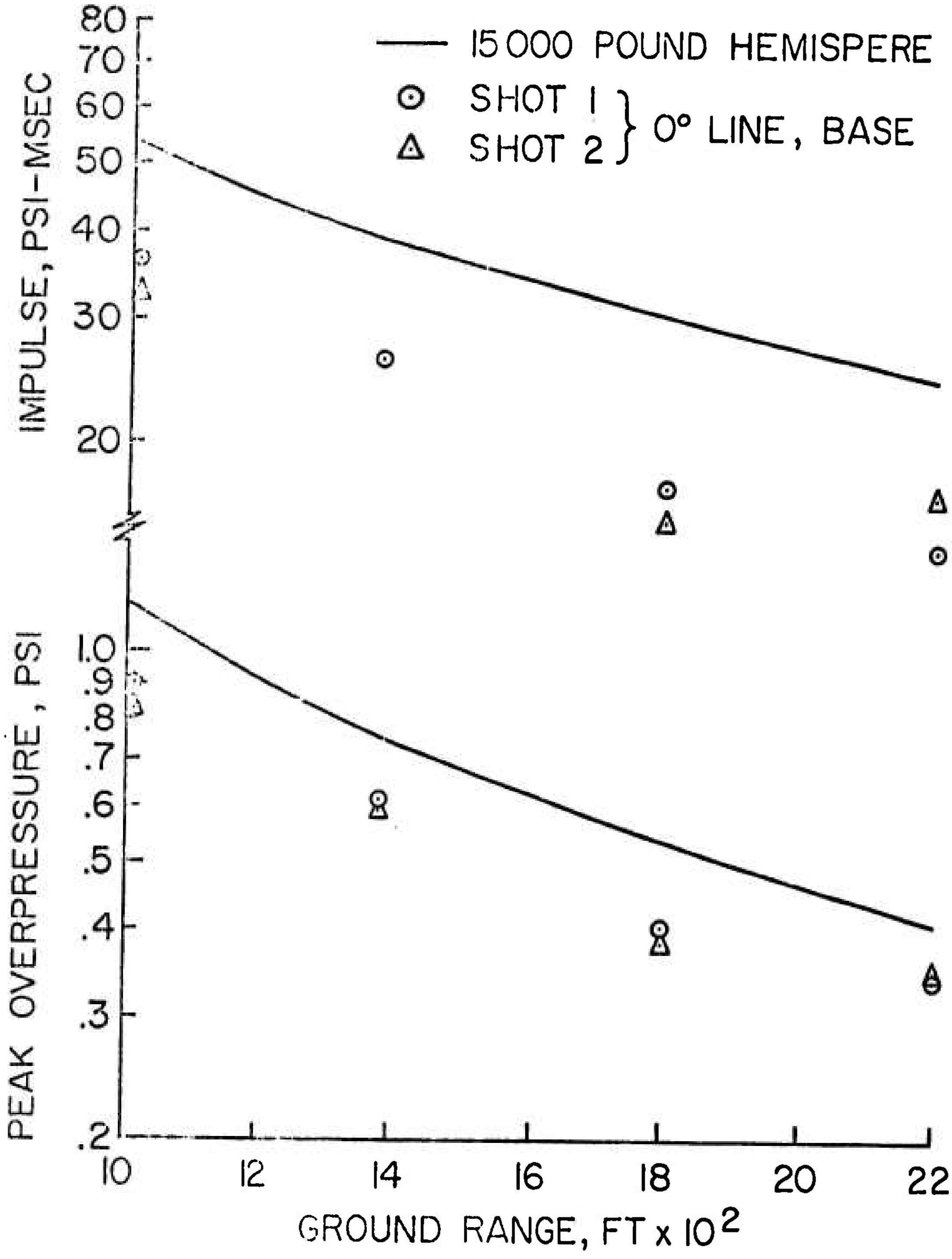


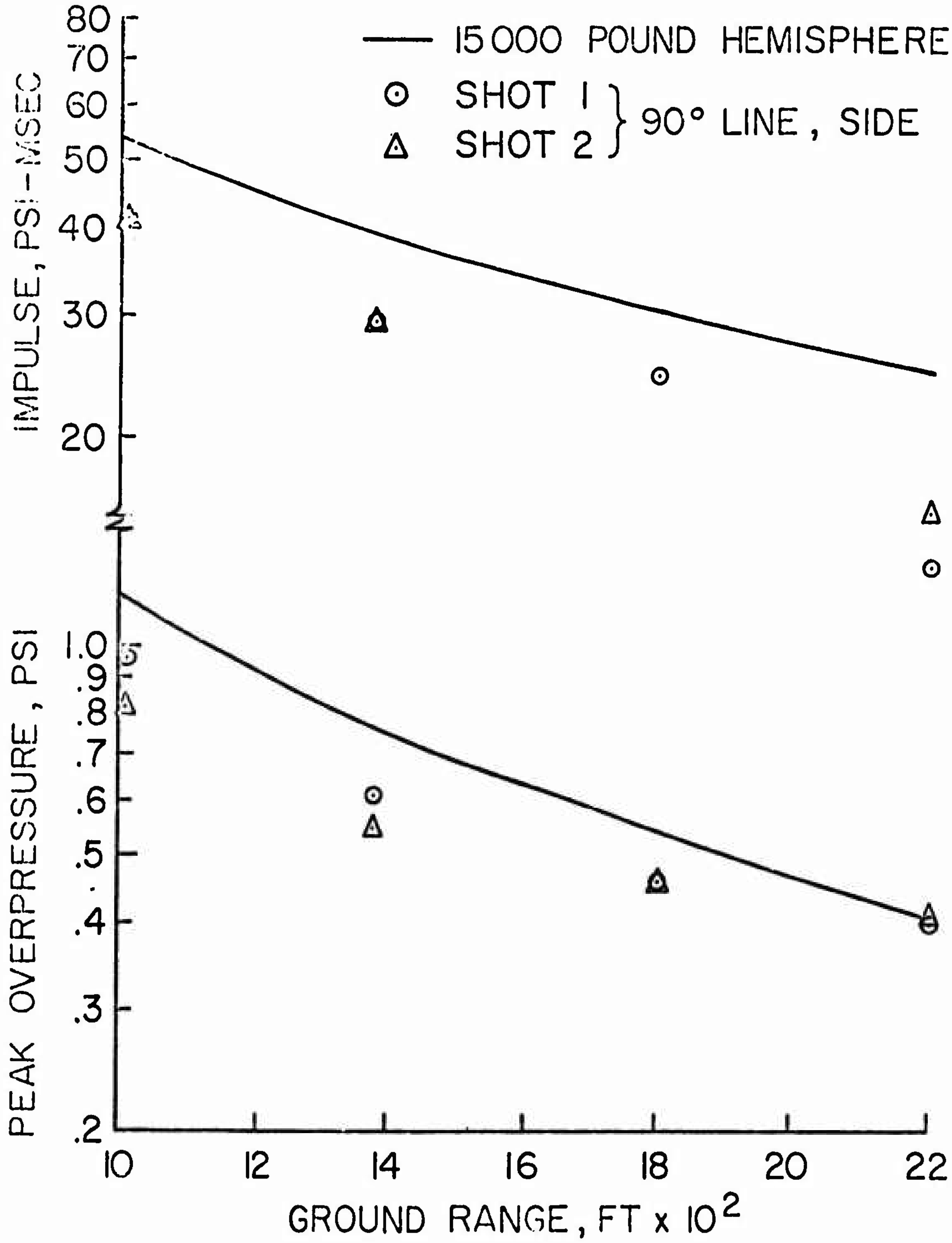
Figure 1 Field Layout for Air Blast Instrumentation

Table 1 SUMMARY OF PRELIMINARY DATA

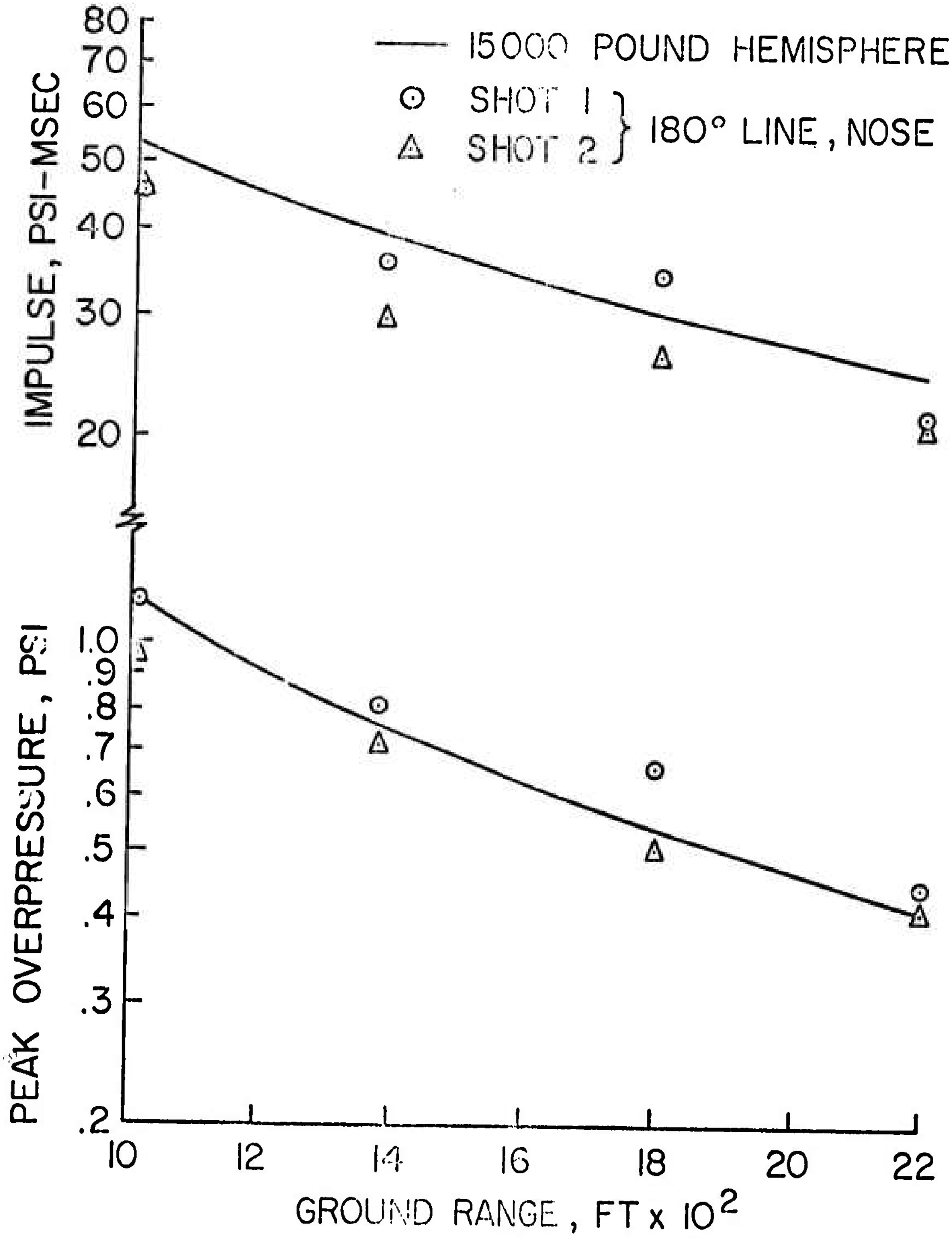
Distance (ft)	0° BASE Over-Pressure (psi)	0° BASE Positive Duration (msec)	0° BASE Positive Impulse (psi-msec)	90° SIDE Over-Pressure (psi)	90° SIDE Positive Duration (msec)	90° SIDE Positive Impulse (psi-msec)	180° NOSE Over-Pressure (psi)	180° NOSE Positive Duration (msec)	180° NOSE Positive Impulse (psi-msec)
SHOT 1									
1010	.900	99.6	36.56	.960	--	--	1.160	104.8	45.10
1330	.620	109.7	26.37	.610	99.6	29.34	.615	114.0	36.04
1800	.403	101.2	17.41	.460	107.9	24.53	.660	119.1	34.64
2200	.340	101.8	14.02	.400	84.5	13.01	.445	119.4	21.52
SHOT 2									
1010	.830	99.1	32.86	.820	96.6	41.61	.960	112.2	45.47
1330	.594	--	--	.550	94.1	29.65	.715	109.9	29.39
1800	.334	102.5	15.54	.463	--	--	.505	130.5	26.32
2200	.350	117.9	16.70	.410	108.4	15.57	.410	123.2	20.61
15000 POUND TNT HEMISPHERE									
1010	1.150	105	53						
1330	.765	115	39						
1800	.550	125	30						
2200	.410	132	24						



15000 POUND HEMISPERE
SHOT 1
SHOT 2
0° LINE, BASE
IMPULSE, PSI-MSEC
PEAK OVERPRESSURE, PSI
GROUND RANGE, FT x 10^2
80
70
60
50
40
30
20
1.0
.9
.8
.7
.6
.5
.4
.3
.2
10
12
14
16
18
20
22



15000 POUND HEMISPHERE
SHOT 1
SHOT 2
90° LINE, SIDE
IMPULSE, PSI-MSEC
PEAK OVERPRESSURE, PSI
GROUND RANGE, FT x 10²
80
70
60
50
40
30
20
1.0
.9
.8
.7
.6
.5
.4
.3
.2
10
12
14
16
18
20
22



15000 POUND HEMISPHERE
SHOT 1
SHOT 2
180° LINE, NOSE
IMPULSE, PSI-MSEC
80
70
60
50
40
30
20
PEAK OVERPRESSURE, PSI
1.0
.9
.8
.7
.6
.5
.4
.3
.2
10
12
14
16
18
20
22
GROUND RANGE, FT x 10²

APPLICATION OF SYSTEMS HAZARD ANALYSIS

Moderator:

R. J. Firenze
NOSC Safety School
Crane, Indiana

1. R. H. Richardson
HERCULES INCORPORATED
Allegany Ballistics Laboratory
Cumberland, Maryland

TOPIC: "Hazards Analysis Through Quantitative Interpretation of Sensitivity Testing"

SUMMARY: Hazards Analysis Technique developed as a practical approach to evaluating processing hazards. This technique is essentially an accident investigation before it happens. (HAT) emphasizes the quantitative assessment of process conditions in engineering terms and establishment of material response to stimuli found in the process.

This presentation was primarily devoted to the discussion of the technique by which to quantitize data in respect to safety, productivity, quantity, and cost.

2. B. J. Garrick
W.C. Gekler
O.C. Baldonado
HOLMES AND NARVER INC.
Los Angeles, California

TOPIC: "Estimating the Risk Involved in the Transport of Hazardous Materials"

SUMMARY: paper attached

3. C.A. O'Malley
TRW Systems- San Bernardino Operations
Norton Air Force Base
California

TOPIC: "System Safety Design Considerations for Toxic Liquid Propellants"

SUMMARY: Safety design considerations from a systems point of view affecting the Post Boost Propellant System Minuteman III (PBPS)

4. R.J. Firenze
NAVORD Safety School
Bloomington, Indiana

TOPIC: "Hazard Analysis of Ordnance Production Systems"

SUMMARY: paper enclosed

APPLYING SYSTEMS ANALYSIS TO ORDNANCE PRODUCTION SYSTEMS

Robert J. Firenze
NOSC Safety School
Crane, Indiana

Systems Hazard Analysis has proven itself to be an essential part of the control process. Over the past decade, this analysis technique has found acceptance by many industrial and governmental agencies in their quest for the location and control of hazards within their operations. The results obtained from the technique have contributed significantly to efficiency, effectiveness, safety and overall mission capability.

The term "systems analysis" suggests a sophisticated analytical approach associated with complicated mathematics and engineering technology. One who interprets it this way is correct from the standpoint that the approach is analytical. However, one does not have to be mathematics-oriented to use the theories and concepts of systems analysis effectively. The only requisites are sound reasoning and logic coupled with an understanding of the effect of hazards on a system's operation.

Although systems safety analysis was originally developed as an engineering tool with which to discover potential failures and the effect of these failures on sophisticated mechanistic systems, the same theories and techniques can be readily applied to finding failures in management systems and, as we will discuss them in this paper, to ordnance production systems.

The primary objective of this paper is to acquaint the hazard control specialist with the methods and techniques of systems analysis, and to describe how he may apply these tools to the evaluation of ordnance production systems. To accomplish this objective, we will view operational systems in such a manner as to uncover hazards or potential hazards in work procedures, materials, equipment, man-machine interfaces, etc., which have the capability of culminating in an accident and/or catastrophic situation.

We will find that Systems Hazard Analysis is nothing more that a formalistic qualitative method for identifying those critical operational methods, techniques, procedures, etc., which have a profound effect upon the successful operation of a system.

In the actual performance of a Systems Hazard Analysis we will be breaking a system (operation) down into its component steps or processes, closely examining these steps to discover potential failures, viewing these failures with respect to their effect on the effectiveness, efficiency and safety of the system, and finally, providing effective countermeasures as required to remedy the undesirable conditions.

The thesis of the Systems Hazard Analysis approach is that hazards may be eliminated by the process of looking for undesired events in the system under study and then finding those failures which are responsible for these events. Table 1 (undesired events checklist) lists undesired events peculiar to an ordnance production system, which are considered potentially injurious

or even catastrophic to the system's operation. These events may be responsible for accidents and system failures.

We will purposely move the direction of the analysis toward finding those elements in the system which can cause problems (failures). We will be, in effect, failure oriented. We will be thinking in terms of failures because (1) it is easier to get mutual agreement on what constitutes a failure, and (2) it is easier to find "holes" or mistakes in something than it is to find all the elements of success.

METHODS OF ACQUIRING INFORMATION

Before we launch into the discussion of the analysis process itself, we will first discuss some of the "rhyme and reason" behind it.

To begin with, we must understand how information is obtained, since the acquisition of "information" concerning hazards is the primary purpose of our mission. Four basic methods of information acquisition will be discussed. They are: (1) experience, (2) testing, (3) conjecture and (4) analysis.

EXPERIENCE

Information gathered as a result of direct past experience is deemed the most highly desirable. Indeed, if we wanted to know exactly how an operation or part of an operation would fail, we would get our most reliable information from the man or men who have operated with that system, who understand all its complexities and problems, and who have themselves discovered the failure and corrected its cause.

Although direct past experience is highly desirable, it is difficult to obtain, especially when we want information either on a system which we are designing ourselves, or one which has not been used sufficiently for data on its inherent hazards to have become known. Since direct past experience is not always available, we must choose the second alternative, that of related experience. When we cannot find the man who has worked with systems exactly like ours, we must look for those who have had experience with systems similar to the one we seek information on. In each case, experience is the most desirable form of information we can obtain.

TESTING

When neither direct nor related experience is available, our second alternative is to "test out" our system under actual conditions, looking for information pertaining to its behavior, and the modes where it may fail. Unfortunately, testing has drawbacks. To begin with, we cannot simulate all the possible failure modes which our system will undergo in actual operation. Second, it may be economically, physically or politically infeasible to test out the system.

CONJECTURE

The third available method of acquiring information is called conjecture. With this method, we find ourselves making decisions almost intuitive in nature, based on an intangible form of data. Decisions come about as a result of an unexplained phenomenon within the mind of the decision maker. Some claim

Although direct past experience is highly desirable, it is difficult to obtain, especially when we want information either on a system which we are designing ourselves, or one which has not been used sufficiently for data on its inherent hazards to have become known. Since direct past experience is not always available, we must choose the second alternative, that of related experience. When we cannot find the man who has worked with systems exactly like ours, we must look for those who have had experience with systems similar to the one we seek information on. In each case, experience is the most desirable form of information we can obtain.

TESTING

When neither direct nor related experience is available, our second alternative is to "test out" our system under actual conditions, looking for information pertaining to its behavior, and the modes where it may fail. Unfortunately, testing has drawbacks. To begin with, we cannot simulate all the possible failure modes which our system will undergo in actual operation. Second, it may be economically, physically or politically infeasible to test out the system.

CONJECTURE

The third available method of acquiring information is called conjecture. With this method, we find ourselves making decisions almost intuitive in nature, based on an intangible form of data. Decisions come about as a result of an unexplained phenomenon within the mind of the decision maker. Some claim

that the decision is brought about by an undefinable process of induction and deduction without a conscious awareness of the process. This method may work under certain circumstances. In fact, it may be the only method available at a given time to solve certain forms of problems. While decisions coming about through conjecture are worth noting, they will not be considered to any great extent for our purpose in analysis.

ANALYSIS

The fourth method of information acquisition is that of analysis, the method which provides the logic for Systems Hazard Analysis.

A workable definition of analysis is a "directed process for the acquisition of specific information pertinent to a given system."(1) Its main purpose is to provide information with which to foster decisions. For the purpose of this paper, we will be using the analysis process for finding information pertaining to failures and their effect on ordnance production systems. However, the same methodology is used for production systems in general.

ANALYTICAL APPROACHES

As previously stated, "analysis" is a method for acquiring information. How we process this information, draw valid conclusions, and make decisions is the subject of our next discussion.

As we learn from the exponents of logic, we think, make judgments and draw conclusions from information acquired from the processes of intuition, induction, and deduction. We use

these approaches singly or in combination in the process of making decisions.

INTUITION

Intuition, as we will learn, differs markedly from induction and deduction. Instead of proceeding logically, a step at a time, intuition provides an instantaneous perceptual insight into a problem, almost extrasensory in nature - a flash of light - happening so fast that the decision maker is unaware that the process is taking place.

In critical situations, the intuitive person can sense those factors necessary for his decision and is able to make the proper judgments to solve the problem immediately.

While we will not overlook the advantages of intuitive decisions under certain circumstances, they will not be emphasized in our analysis process. The reason being that "intuition" is not repeatable. We cannot and must not rely on intuition to make decisions, especially when the decision may have a catastrophic effect on the operation of our system. Instead we will rely on one or both of the following approaches.

INDUCTION

The inductive process, based on predictions from observable data, can tell us "what" can occur and is the basis for what is called the "single thread analysis", a form of analysis which allows us to consider the effects of failures on a system's operation from the standpoint of its components, their failure in

a particular operating state, and finally, the effect of the component failure on the system. The single-thread type analysis forms the basis of the Systems Hazard Analysis.

In the single thread analysis (Fig. 1), we are in effect looking at all the components of our system, postulating the states of existence of these components, and asking ourselves what happens if the components fail in a certain mode and what the effect on the system will be.

Component	Component Failure Mode	System Operating State	Effect of Component Failure On System	Remarks
MTF Fuze	Detonates during assembly	While being threaded into round	Detonation - system destroyed	Fuze armed - projectile impact with floor

Fig. 1

Systems Hazard Analysis, Fault Hazard Analysis, Failure Mode Effect Analysis, Failure Mode, Effect, and Criticality Analysis and other similar types also make use of the inductive approach.

DEDUCTION

In deductive reasoning, we start with a theory, then apply it in an attempt to find the causes of system failures.

In our dealings with the Systems Hazard Analysis, we will be using the inductive approach.

BENEFITS OF SYSTEMS HAZARD ANALYSIS

The benefits derived from a Systems Hazard Analysis are countless. The following are examples of some of these benefits.

(1) Identifying hazardous elements, conditions, and potential accident sources.

(2) Determining where these hazards are in the system.

(3) Determining the significance of their potential effect on the system's operation.

(4) Providing information with which effective control measures may be established.

(5) Determining the physical and mental qualifications required of a man, including his motor skills, for the specific task he is involved with.

(6) Discovering and eliminating procedures, techniques, motions, positions, and unsafe actions that are potentially hazardous.

(7) Locating areas for further analysis.

(8) Identifying possible interface problems which may result in an accident.

(9) Uncovering special areas of safety consideration such as system limitations, risks, etc.

PRELIMINARIES TO ANALYSIS

The remainder of this paper is devoted to the specific application of Systems Hazard Analysis to an ordnance production system. Before we get involved with the application of the

analysis techniques, certain points must be understood.

I. Definitions

Safety: - "Freedom from those conditions that can cause injury or death to personnel, or damage to or loss of equipment or property."[2]

System: - The word "system" as mentioned several times during this discourse, will be defined as a "composite of operational and support equipment, personnel, and facilities, which form an entity capable of and/or supporting an operational role within the constraints of a given environment."[2] More simply stated, a system is any purposive entity acting along with its environment. A unique characteristic of a system is that it must exist for a reason.

System Safety: - "The optimum degree of safety within the constraints of operational effectiveness, time and cost, attained through specific application of system safety management and engineering principles throughout all phases of a system's life cycle."[2]

Man-Machine Systems: - Our efforts will mainly revolve around man-machine systems. A workable definition of a man-machine system is "an operating combination of one or more men interacting with one or more machine components, whose objective is to produce a desired outcome from given inputs within the constraints of a given environment."[3]

Efficiency and Effectiveness: - Before attempting the analysis it is critically important that the analyst know exactly how the

system functions. It is mandatory that he understand the system by viewing it as a whole entity, as well as a series of integrated subsystems, defining its objective, understanding its requirements, and determining at what levels of efficiency and effectiveness it is performing, before he can determine those elements which will be required to improve the system's operation.

Two words have been mentioned here which require our close attention. Oftentimes, these words are misunderstood and, even worse, used interchangably. The first is "efficiency." When we consider the efficiency of a system, we are in effect asking if the system is making optimum use of its resources to achieve its desired output. Rarely will we find a system operating at 100% efficiency. More often, because of physical and economic limitations, systems are forced to operate at lower levels of efficiency.(5)

The second word is "effectiveness." When we look at the system in terms of effectiveness, we are in effect asking ourselves, "is this system accomplishing its objective?" When answering this question we must be cognizant of the fact that a system may be highly effective while not coming up to the highest levels of efficiency. In other words, a system does not necessarily have to be efficient to be effective or vice versa.(5)

II. The Flow Process

A valuable method of acquiring information about the system is to review the flow process. This technique will enable the analyst to gain a more thorough comprehension of the subsystems,

methods, processes, transfer operations, inspectional techniques and man-machine interfaces pertinent to the system under analysis. The flow process, as illustrated in Figure 2, is designed to depict the system's operation, and to make comprehensible its methods, process, etc. Each step is viewed as a subsystem in its own right.

III. Selecting the Operation for Analysis

The responsibility for selecting the particular operation to be analyzed rests with the hazard control manager himself. In an organization where many hazardous operations exist, or where potential hazards seem to be inherent in all operations, such as an ordnance production system, certain available clues will serve as guides. These known data are:

1) Injuries

The fact that injuries are prevalent in a specific operation is often a signal that something is wrong with the system's operation. For example, human error, equipment failure, environmental failure, etc. may be setting up hazards responsible for accidents.

2) Recurring Accidents

Operations with a history of recurring accidents responsible for lost-time injuries, mission interruption, and/or excessive costs, etc., are candidates for hazard analysis.

3) Operations with "Known Potential"

Some operations are seemingly hazardous by nature. Even

though an accident has never occurred, the fact that a severe one could occur is sufficient reason for analysis.

4) Interference - Mission Delay

If a survey of the operation indicates areas where work methods and/or practices are interfering with the effective accomplishment of the operational task (breaking equipment, etc.), it becomes obvious that a hazard analysis is required.

Careful consideration of the above factors will serve to determine the order and priority to be assigned in selecting the operations for analysis.

IV. The Concept of Boundaries

Before we are able to conduct an analysis, we must limit ourselves to a particular segment of the overall system. The necessity of establishing limits around a specific segment of a system gives credence to what is referred to in "system's language" as the "boundary concept." The use of boundaries enables the analyst to "cut out" a segment of the universe which he wishes to focus his attention on by establishing a hypothetical line around it. Boundaries are also useful because they restrict the scope of the problem to a size commensurate with the time available and the cost of the analysis. To effectively "bound" the system, the analyst must make a subjective appriasal of the overall system prior to actually working on the problem.

The dotted lines in Figure 2 indicate the boundary for our system. Figure 3 illustrates a more detailed description of the boundaries of the system under study. These boundaries were

established because existing data indicated that hazards were inherent in this phase of the system's operation.

The danger in developing boundaries is that it is possible to be carried into back alleys of distantly related problems.(4)

The need to appraise familiar or unfamiliar problem areas in establishing boundaries and, subsequently, to investigate problems makes it desirable to explore the process by which this should be done.

The Systems Hazard Analysis as it will be applied to ordnance production systems will rely on the process of inductive reasoning, the process mentioned earlier, whereby conclusions are drawn by generalizing from many specific cases. When we speak of the inductive process with respect to systems analysis, we are essentially speaking of a methodology with which we scrutinize the entire system in an attempt to "ferret" out all the possible ways in which its components could fail, and what effect the consequences of these failures will have on the overall system's operation. Of course, we cannot be so naive as to think we will ever find all the ways in which our system may fail. Instead we must be satisfied with the discovery of as many failures as is possible at the time of the analysis with the information on hand at that time.

When we make a hazard analysis, we are basically building a data bank of systems failures. This data bank will serve to provide the information for all future decisions concerning the safety and reliability of the system.

FUNCTIONS OF SYSTEMS HAZARD ANALYSIS

The overall functions of a Systems Hazard Analysis may be grouped into the following four categories:

(1) Systems Hazard Analysis must be an integral function in all operational designs. It is during this design stage that effective controls can be applied early enough to eliminate causative factors responsible for failures in the system's operation. The data acquired from analysis also serves to identify and control deficiencies in the system's further development.

(2) Safety review of an existing system to determine if its design, operation, procedures, etc., are adequate from the standpoint of safety.

(3) Evaluation of all proposed modifications or redesign of the system's operation and/or its equipment to insure that no new safety problems are created.

(4) Continual monitoring of the system's operation to insure that loss control requirements are indeed adequate and that they are being compldied with.

ANALYSIS CHECKLISTS

Many systems are similar from the standpoint that their components, processes, man-machine interfaces, environment, and mission, lend themselves to analysis by virtue of pre-established criteria. Based on this premise, special checklists, designed to cover general hazardous elements, have been developed. See Tables 1, 2, 3 and 4.

It is not intended, nor is it even suggested, that the checklists cover all possible hazardous elements. They do, however, provide guideposts around which more specific inquiry may be made and relationships drawn.

Tables 1, 2, 3 and 4 represent lists of general undesired events, hazardous conditions, and hazardous energy forms which are pertinent to the evaluation of ordnance production systems.

The analyst will use these lists to discipline his thinking while considering each function under analysis.

THE APPROACH

The first step in the analysis process is to reduce the overall operation into convenient functions (sub operations, each representing a particular step in the operation). Each sub operation is then analyzed individually and "all" hazardous elements in or associated with the operation identified. Even though we are seemingly concentrating on one function at a time, we must always remember that each of these steps is part of the overall system under study, and not an isolated entity. Each step has effect upon other steps in the overall operation. These interfaces must be considered as we pick our way through the analysis.

The key point to remember while working through the analysis is to start at the output of the system (completed mission), and then determine those failures which may detract from its successful completion.

The analyst must be thoroughly familiar with the procedures involved in the operation before he begins. His first step is

to draw a flow diagram which describes each step in the overall operation from the time it starts through its completion. Each step must be broad. Details are omitted. It is important that the analyst not make the breakdown too detailed since at this stage of the process, details would only serve to cause confusion and impede the analyst from making progress.

A simple operational breakdown sheet can be made with relative ease to aid the analyst. As is illustrated in Figure 4, four basic symbols are used to depict the stages in the flow process.

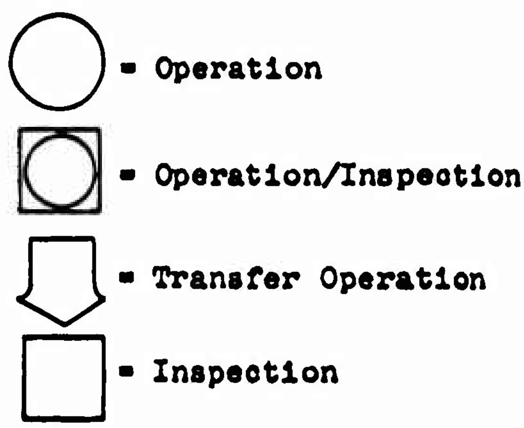


Fig. 4

Any operation can be broken down by using these standard symbols. If the operational steps are properly defined, it will be comparatively easy for the analyst to focus his attention on them and analyze them in depth.

Once the operation is broken down into successive steps or functions, the next step is to acquire an analysis matrix, a special format designed to facilitate the recording of data pertinent to the system under study. This particular format has proven its usefulness in applied situations. As is indicated in Figure 5, the format provides space for recording particular relevant information concerning the identity of hazards, their causes, the effects of these hazards on the system, and finally, the corrective measures required to remedy the situation.

The following descriptions are indicative of the information required for each category in the format:

(1) Function - the particular sub operation being analyzed.

(2) Mode - identifies the system phases which are applicable.

(3) Hazardous Element - identifies the elements, in the hardware of function being analyzed, which are inherently hazardous.

(4) Hazardous Condition - the condition which has the capability of causing an accident.

(5) Triggering Event - that element which could initiate (trigger) the hazardous condition into becoming a potential accident.

(6) Potential Failure - the potential failure (accident) which could result from the hazardous conditions.

(7) Effect - the possible results of the potential accident.

(8) Hazard Classification - this category provides a qualitative measure of the hazard's effect and is categorized as follows:

Category I - NEGLIGIBLE: Conditions which will not result in personnel injury, system damage, or mission interruption.(2)

Category II - MARGINAL: Conditions which can be corrected or controlled without injury to personnel or major system damage or mission interruption.(2)

Category III - CRITICAL: Conditions which will cause personnel injury or major system damage, or will require immediate corrective action for personnel or system survival.(2)

Category IV - CATASTROPHIC: Conditions which will cause death or severe injury to personnel, system loss, and/or mission failure.(2)

(9) Corrective Action - this category is reserved for listing those control measures necessary to eliminate or control the identified hazardous condition and/or potential accidents. Corrective actions will fall into the following categories:

1) Engineering design of tools, equipment, apparatus
2) Incorporation of safety devices
3) Procedural revisions
4) Personnel requirements
5) Supervision.

USING THE MATRIX

Fig. 5 illustrates a partially completed Systems Hazard Analysis matrix. In actual practice each function in the operations would be viewed in accordance with the criteria as listed on the checklists. These data are purposely designed to guide the analyst so that

he considers as many of the hazard criteria as possible in his analysis of the safety of each function. The completed matrix will contain information on every function in the overall operation. The information will be used as the basis for providing effective controls.

RESULTS OF SYSTEMS HAZARD ANALYSIS

The information generated by a Systems Hazard Analysis is a highly significant data source. Data resulting from a thorough analysis of all possible failure modes provide the basis for design, redesign and the incorporation of safety and fail-safe features, which render failures in the system less probable and less critical in terms of overall performance. Such data can and should serve as valuable reference material in uncovering hazards and potential hazards, and aid in the prevention of repeating those discrepancies which have already been defined.

Other results of the Systems Hazard Analysis can be adequately grouped into the following categories:

(1) Eliminating significant hazards uncovered by the analysis through equipment, personnel, or procedural adjustments.

(2) Reducing or controlling those hazards to personnel and equipment which cannot be eliminated.

(3) Isolating hazardous operations from other activities, areas, and personnel.

(4) Providing control measures where failures would adversely affect the system or cause a catastrophic event through personnel

injury, equipment damage, or inadvertent operation or movement of critical equipment.

(5) Designing, locating, and arranging equipment components so that access to them by personnel during operation, maintenance, repair or adjustment will not expose them to such hazards as electrical shock, cutting edges, toxic atmospheres, etc.

(6) Avoiding undue exposure of personnel to physiological and psychological stresses which might cause errors leading to injuries.

(7) Installing effective standardized warning systems on hazardous components, equipment, etc., for the protection of personnel in the event of system failure.

USES OF SYSTEMS HAZARD ANALYSIS

Throughout this paper analysis has been used primarily as an engineering tool for system design purposes, system improvement, and to appraise a system's operational effectiveness and safety. While it is used most commonly for these functions, it does however serve other valuable purposes.

Education

The data acquired from a hazard analysis is particularly useful as an aid for teaching personnel about a particular system in terms of its operation, man-machine requirements, where and how failures can occur, what effect these failures would have on the system if they should occur, and most important, the subsystems which need constant monitoring to assure continued safety.

Investigation

A Systems Hazard Analysis is also extremely useful for accident investigation. By reasoning backwards from the predetermined undesired events, and the conditions responsible for these events, the investigator is in a more desirable position to assess the system prior to the accident and to find the hazardous elements and/or human failures which were responsible for the problem.

Communication

By recording data pertaining to a system, in a logical manner, comprehendable to others, the analyst is more readily able to convey his findings.

FAULT TREES

The information acquired from a hazard analysis may be taken a step further. By interjecting the information into a logic diagram, or as it is commonly called, a Fault Tree, the analyst is able to pinpoint the failures which contributed to the cause of the undesired event or fault as uncovered in the preliminary analysis. In effect, a Fault Tree is a straightforward process for telling how a particular failure can occur within a system. Beginning with a foreseen undesired event, the Fault Tree traces the sequences of possible events which could lead to the unwanted happening. See Figure No. 6.

Development of a Fault Tree requires greater insight and knowledge of a system's operation and the analysis process. For a more thorough understanding of the Fault Tree concept, I recommend reading the series by Recht in National Safety

News, on the subject of Fault Tree Analysis.

When selecting the proper countermeasure to control a problem uncovered in the analysis, the analyst should consider the following four engineering control principles, ranked according to their desirability: (1) eliminating the hazard at its source by correcting mechanical and physical hazards, (2) intercepting or controlling the hazard before it reaches the man (shielding, guarding), (3) providing personal protective devices where controls are inadequate, and (4) instructing employees relative to specific job procedures. In addition to the previous possibilities, combinations of each may be employed to reach an acceptable solution.

Before an attempt is made to develop numerous solutions to the hazards associated with an existing operation, consideration should be given to the possibility that there might be an entirely different way of performing the task which will eliminate the hazard.

When a change is made, this change should be closely studied to determine if the new solution will indeed solve the problem and not, in fact, create a new one. Oftentimes, in the process of eliminating existing hazards, new ones are formed.

Upon completion of the Systems Hazard Analysis, the information must be implemented into the organization's work techniques. Procedures and techniques must be made known to the personnel who are responsible for the system's function.

The person who carries out a Systems Hazard Analysis will find that, in addition to all the benefits previously mentioned,

it enables him to learn more about the system he supervises, and causes him to gain a more thorough insight into operational techniques, human and machine capabilities, and overall system functions.

REFERENCES

(1) Haasl, David F., from a seminar on Systems Safety at the University of Washington, Aug. 1969

(2) Military Standard 882,"Requirements for Systems Safety Program and Association Subsystems and Equipment" - July 15, 1969 - D.O.D.

(3) McCormick, E. J., "Human Factors Engineering" - McGraw-Hill, 1964

(4) Optner, S. L. "Systems Analysis for Business Management" - Prentice-Hall, Inc., 1968

(5) Firenze, R. J., "Systems Approach to Safety System Evaluation" - National Safety News, Feb. 1970

(6) Recht, "Fault Tree Concepts" - National Safety Council, 425 North Michigan Avenue, Chicago, Ill. 60611

TABLE OF UNDESIRED EVENTS

1. Fire
2. Explosion
3. Detonation
4. Release of toxic material
5. Injury to man
6. Death of man
7. Interruption of production
8. Loss of production equipment
9. Loss of production facility
10. Release of pollutants

Table 1

HAZARDOUS ENERGY FORMS

1. Chemical Reaction

    a. Unstable materials - violent decomposition
    b. Reaction of materials with moisture
    c. Reaction of materials with acidic contaminants
    d. Reaction of materials with caustic contaminants
    e. Inter-reaction of materials (incompatability)
    f. Effects of temperature and pressure

2. Heat

    a. Heating devices
    b. Electrical equipment and fixtures
    c. Electromagnetic radiation
    d. Mechanical
    e. Chemical reactions
    f. Weather

3. Open Flames or Sparks

    a. Electrostatic discharge
    b. Electrical failures
    c. Mechanical sparks
    d. Open flame devices
    e. Chemical reaction
    f. Heat
    g. Lightning

4. Mechanical

    a. Impact
    b. Friction
    c. Stress (shear, pinching, crushing, grinding, etc.)
    d. Static loading

Table 2

TYPICAL HAZARDOUS CONDITIONS

A. MAN

1. Is exposed to:

   a. Toxic materials
   b. Irritants
   c. Excessive or improper lifting
   d. Slippery, uneven or rough floor surface
   e. Falls from elevated surfaces
   f. Contact with hot materials or surfaces
   g. Rough, sharp or cutting surfaces
   h. Electrical shock
   i. Mechanical hazard points (nip points, shear points, crushing points, etc.)
   j. Noise or vibration
   k. Thermal stress
   l. Radiation - ionizing or nonionizing
   m. Weather
   n. Fire, explosion or detonation

2. Physical, psychological and physiological stressors:

   a. Drugs, medicines
   b. Alcohol
   c. Intoxicating vapors, dusts or fumes
   d. Fatigue

B. MATERIAL IN PROCESS

1. Becomes more sensitive - less stable

   a. Due to reaction with contaminants
   b. Due to crystal growth
   c. Due to separation of ingredients
   d. Due to side reactions
   e. Due to increased temperature or pressure
   f. Physical stimulation

2. Is exposed to:

   a. Solid contaminants
   b. Mechanical shock
   c. Friction
   d. Pinching, shearing, grinding or compressive actions
   e. Excessive heat
   f. Freezing
   g. Open flames or sparks
   h. Radiation
   i. Electrostatic discharge
   j. Moisture

Table 3

TYPICAL SOURCES OF HAZARDOUS ENERGY IN SUBSYSTEM OPERATION

1. Chemical Reaction:

   a. Violent decomposition of explosives

      (1) at elevated temperature
      (2) at low temperature
      (3) crystalline growth - components of Comp B

         (a) RDX
         (b) TNT

   b. Aluminum powder + moisture
   c. Comp B + acidic contaminants
   d. Comp B + caustic contaminants

2. Heat:

   a. Steam

      (1) failure of pressure controls
      (2) Inadvertent setting of steam controls at high pressure

   b. Electrical equipment and fixtures

      (1) low voltage short
      (2) unprotected light or other electrical fixture
      (3) electric motor overloaded
      (4) power source - voltage drop
      (5) improper for hazard present

   c. Electromagnetic radiation from

      (1) motor vehicle radios
      (2) train radios
      (3) ham radios
      (4) radar
      (5) aircraft

   d. Mechanical heat from

      (1) failure of shaft bearings
      (2) inadequate clearance of moving parts

   e. Chemical reactions producing heat build-up without detonation or flaming

Table 4

3. Open Flames or Sparks

a. Electrostatic discharge from

(1) charge generated on man
(2) charge generated on equipment
(3) charge generated on materials

b. Electrical failure

(1) direct short in wiring
* (2) breakage of light globe or electrical enclosure
* (3) water in conduit
(4) opening electrical enclosures

c. Mechanical sparks from ferrous tools striking concrete or equipment

d. Open flame devices

(1) maintenance work involving welding, soldering or other open flame or spark producing devices
(2) smoking, lighters or matches

e. Chemical reactions producing flaming

f. Heat causing chemical reaction to occur

g. Atmospheric electrical disturbance

(1) Lightning striking building
(2) Induced electrical charge from atmospheric disturbance resulting in interior discharge

4. Mechanical

a. Impact

(1) dropped tools or materials
(2) striking agitator shaft to remove build-up
(3) valve closing in discharge lines
(4) explosive particles impinging in dust exhaust system

b. Friction

(1) materials spilled on floor and workers walking over them
(2) agitator blade rubbing kettle wall
(3) agitator shaft and housing
(4) conveyor drive mechanism
(5) sliding containers over a contaminated surface
(6) particles in dust exhaust system

c. Stress (shearing, pinching, etc.)

(1) due to lack of clearance between agitator blade and kettle wall
(2) in conveyor system - gear box and drive mechanism
(3) discharge valve operation
(4) workers walking over spilled materials
(5) carts rolling over spilled materials
(6) solid foreign material in kettle such as glass, rocks, nuts, bolts, etc.:

(i) entry in explosives
(ii) entry in transfer of explosives
(iii) entry in kettle room from kettle appurtenances
(iv) from broken windows or light fixtures

FLOW DIAGRAM OF MK 82, 500 LB LOW DRAG BOMB PROCESS

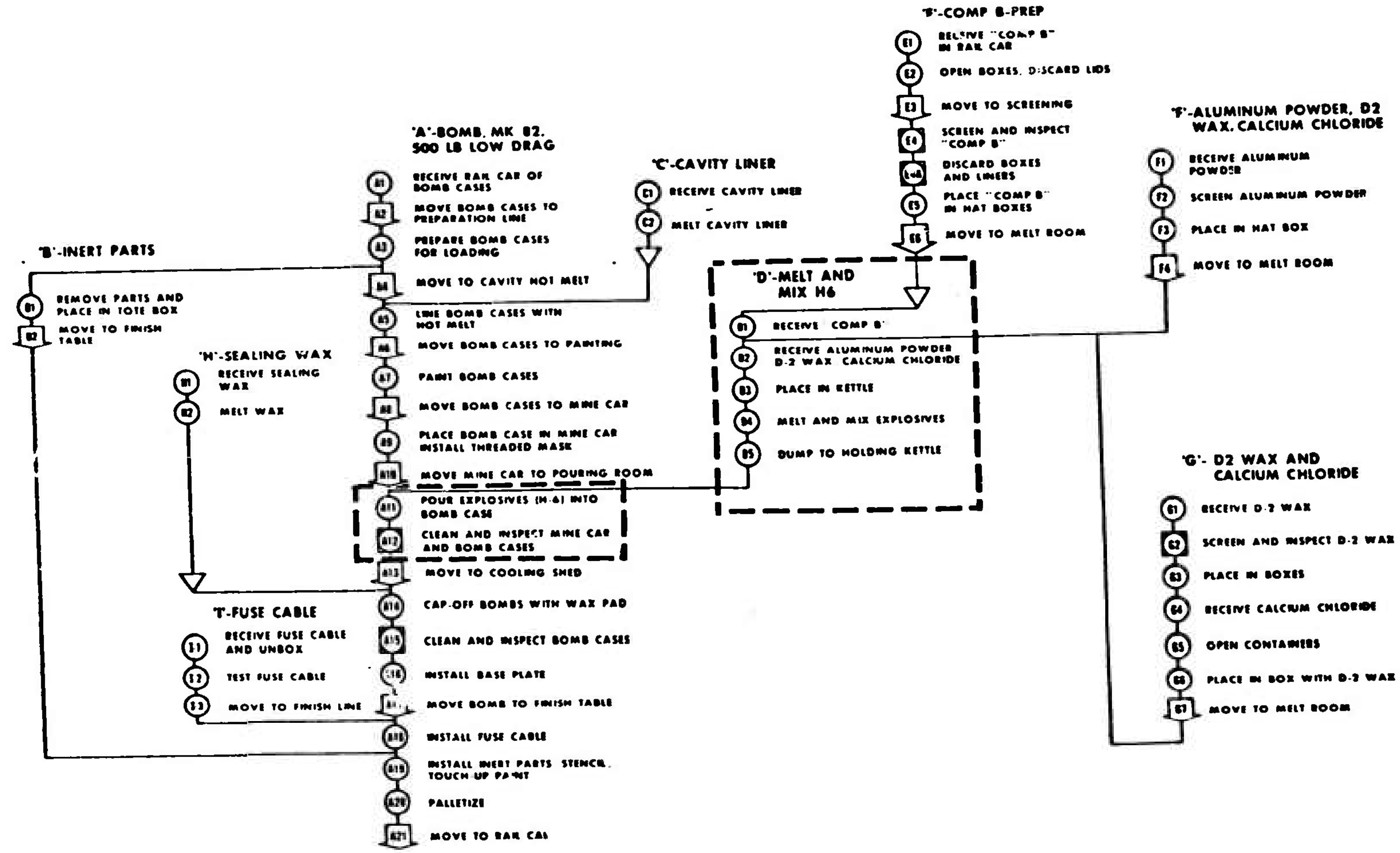


Figure 2

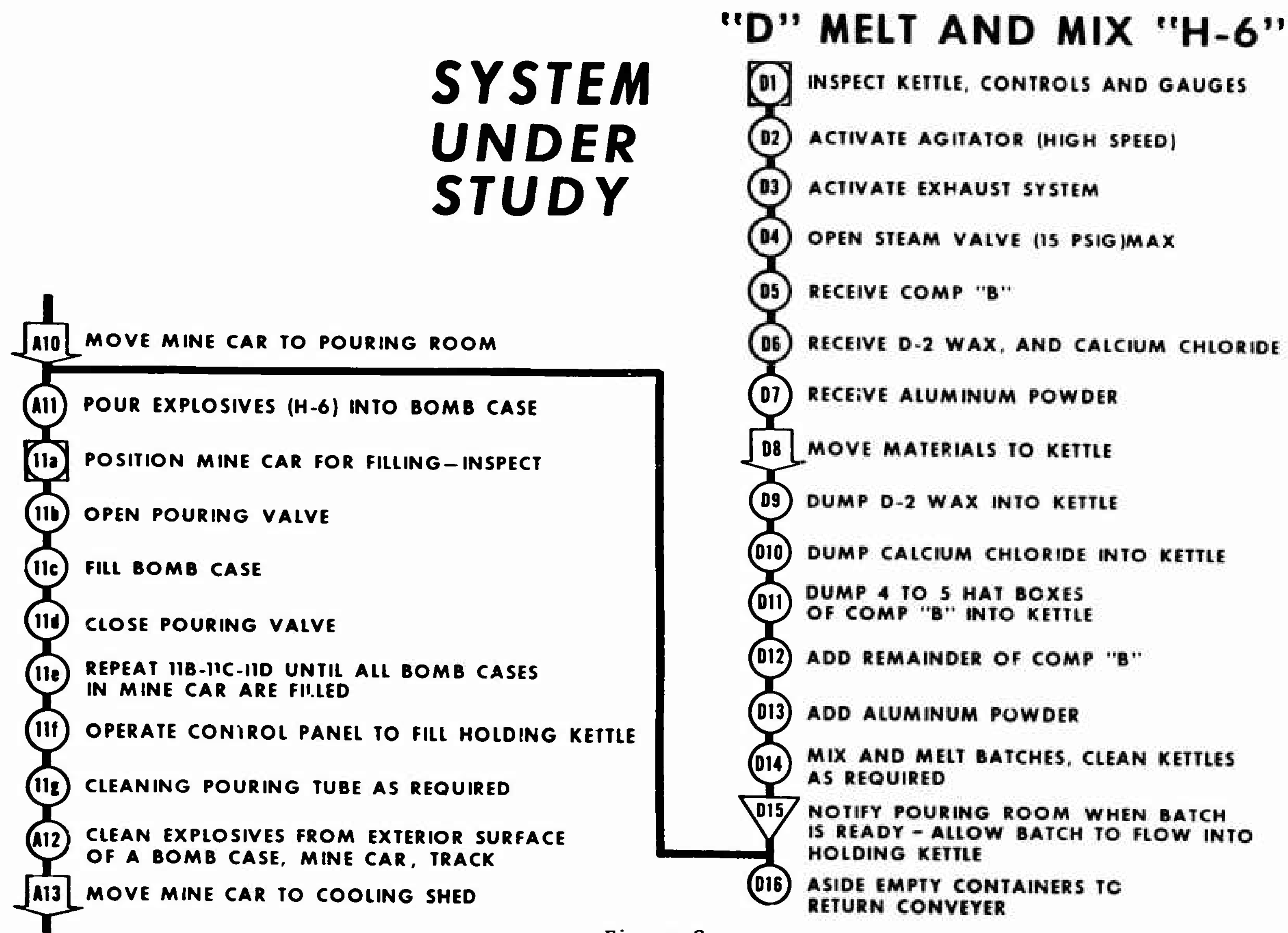

SYSTEM UNDER STUDY
"D" MELT AND MIX "H-6"
D1 INSPECT KETTLE, CONTROLS AND GAUGES
D2 ACTIVATE AGITATOR (HIGH SPEED)
D3 ACTIVATE EXHAUST SYSTEM
D4 OPEN STEAM VALVE (15 PSIG)MAX
D5 RECEIVE COMP "B"
D6 RECEIVE D-2 WAX, AND CALCIUM CHLORIDE
D7 RECEIVE ALUMINUM POWDER
D8 MOVE MATERIALS TO KETTLE
D9 DUMP D-2 WAX INTO KETTLE
D10 DUMP CALCIUM CHLORIDE INTO KETTLE
D11 DUMP 4 TO 5 HAT BOXES OF COMP "B" INTO KETTLE
D12 ADD REMAINDER OF COMP "B"
D13 ADD ALUMINUM POWDER
D14 MIX AND MELT BATCHES, CLEAN KETTLES AS REQUIRED
D15 NOTIFY POURING ROOM WHEN BATCH IS READY - ALLOW BATCH TO FLOW INTO HOLDING KETTLE
D16 ASIDE EMPTY CONTAINERS TO RETURN CONVEYER
A10 MOVE MINE CAR TO POURING ROOM
A11 POUR EXPLOSIVES (H-6) INTO BOMB CASE
11a POSITION MINE CAR FOR FILLING—INSPECT
11b OPEN POURING VALVE
11c FILL BOMB CASE
11d CLOSE POURING VALVE
11e REPEAT 11B-11C-11D UNTIL ALL BOMB CASES IN MINE CAR ARE FILLED
11f OPERATE CONTROL PANEL TO FILL HOLDING KETTLE
11g CLEANING POURING TUBE AS REQUIRED
A12 CLEAN EXPLOSIVES FROM EXTERIOR SURFACE OF A BOMB CASE, MINE CAR, TRACK
A13 MOVE MINE CAR TO COOLING SHED

Figure 3

HAZARD ANALYSIS

FUNCTION	MODE	HAZARDOUS ELEMENT	HAZARDOUS CONDITION	TRIGGERING EVENT	POTENTIAL FAILURE	EFFECT	HAZARD CLASS	CORRECTIVE ACTION
Filling Bomb Cases	Pouring Operation	Molten H6	Overflow of Kettle	Failure of Level Control Valve	Spillage of Explosive	Burns Injury to Personnel	III or IV	1) Fail-safe level control valve for holding Kettle 2) Protective equipment - Hard Hats - Face Shield - Conductive Boots - Coveralls - Gloves

Figure 5

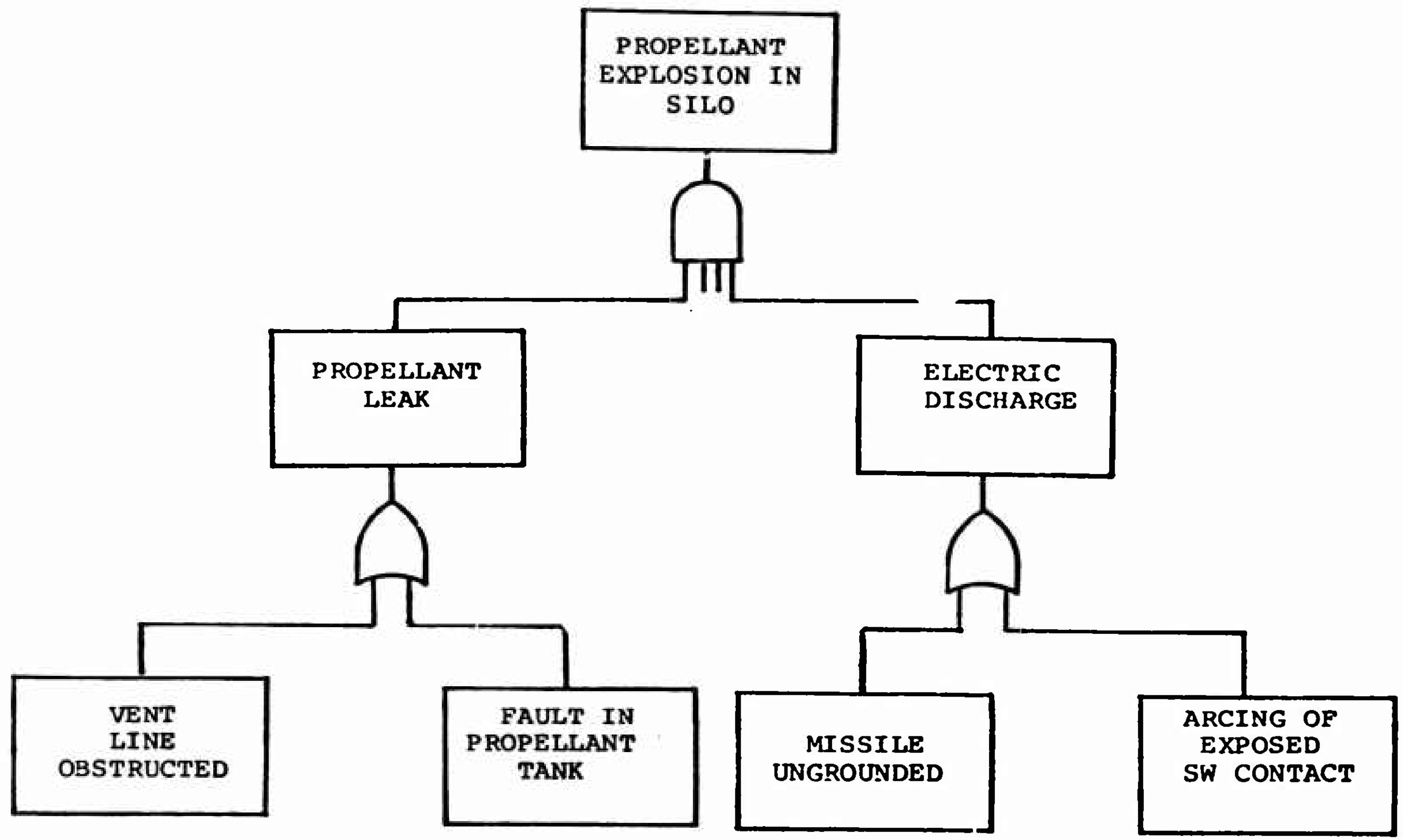

PROPELLANT
EXPLOSION IN
SILO
PROPELLANT
LEAK
ELECTRIC
DISCHARGE
VENT
LINE
OBSTRUCTED
FAULT IN
PROPELLANT
TANK
MISSILE
UNGROUNDED
ARCING OF
EXPOSED
SW CONTACT

Figure 6

ESTIMATING THE RISK INVOLVED IN TRANSPORT OF HAZARDOUS MATERIALS

by
B. John Garrick
Orlino C. Baldonado
Willard C. Gekler

ABSTRACT

This paper describes a model for quantitatively estimating the risk when handling and transporting hazardous materials. The estimated risk values can be used to evaluate the effectiveness of changing the container design, handling procedures, method and path of transport, as well as testing and inspection procedures. The ultimate objective is minimization of public exposure when transporting hazardous materials such as industrial gases.

Presently, only the transport of hazardous materials capable of atmospheric diffusion is considered. The measure of risk which is calculated by the model is the expected number of people affected by the hazardous material per trip. The model calculates the probability of release and the expected area affected by various dose levels or concentrations given that there is a release of hazardous material. Coupling the population density with the areas gives the risk measure.

Many factors are considered in estimating the effect of a hazardous material release. Two distinct time decay constants can be used corresponding to whether the material is inside or outside the transport container. These decay constants account for the change in activity of the materials while in storage and the effect of atmospheric properties such as solar radiation, humidity, and heat. Reduction factors are included in the model to account for barriers around the container which preclude release of hazardous materials. The portion of material released to the atmosphere is then calculated by combining the preceding factors with the leakage rate and aerosolization factor for the material/container system.

The effect of the release is computed as the expected areas subjected to various concentrations or dose levels of the hazardous materials. Diffusion equations are used to determine the concentration distribution after the release. The concentration numbers for each area are next related to the probability of pertinent physiological reactions, given that there are people in the area.

Probabilities are computed for events (accidents, container leaks, environmental control system failures) leading to a release at any point in the transport path, the path being divided into nodes and links. These probability estimates are developed by dividing the path into nodes and links and assigning vehicular types and accident frequencies to each path element.

The probability is calculated by a Monte Carlo technique. In effect, this technique simulates the interaction of handling procedures and transportation mode with the container design during the time intervals established by the transport path.

By multiplying the probability of release, expected areas for various concentrations, the probability of physiological reaction, and the population density, a measure of risk is obtained.

Some numerical results of the methodology are given to illustrate the use of the model to determine the effect of changing container design, path, transit time, and mode of transport.

1. INTRODUCTION

It is a fact of life that many useful substances which are also hazardous to human health must be transported through uncontrolled areas. Examples of these are chlorine, ammonia, and other noxious materials which exist in the gaseous or aerosolized state at ambient conditions. These materials move on the highways, railroads, waterways, and airways daily. It is also a fact that while these materials are transported, little is known about the quantitative risk they impose on public health until extensive in-use experience has been obtained. Most papers that deal with the risk involved are concerned with the release mechanisms and the release rates,[1,2] whereas others deal with the atmospheric dispersion.[3,4] Few deal with the overall problem of estimating a quantitative risk in terms of the number of casualties per trip based on both the probability and effects of all identifiable release mechanisms. This paper describes an a priori risk evaluation methodology which permits quantitative risk estimates. The calculations can be made before actual transport of a hazardous material, before use of new transport container systems, and before employment of new methods or paths of transport. A measure of the risk can thus be used to evaluate various schemes. The risk methodology was developed under contract to the U. S. Army.[5]

The methodology is based on identifying parameters pertinent to the hazardous material and its complete transport system in a form suitable for input to three computer programs. The first program, MINCUT, estimates the probability of a release; and the second, BWARE, calculates the effect of the release. The third program, HAZTRANS, is the main program. It uses MINCUT and BWARE as subroutines and is used to summarize the input and output information for the risk calculations.

Potential applications of this methodology include the following:

a. Evaluation of cost-benefit trade-offs where effect is measured in terms of cost rather than effect on human health.

b. Evaluation of alternate transportation modes and alternate paths for transport of hazardous material.

c. Evaluation of the effect on the risk of alternate container design, handling procedures, and inspection techniques.

2. FRAMEWORK OF THE METHODOLOGY

It is assumed that a certain material is to be moved from some origin to some destination in a prescribed series of actions known as the transport sequence (TS). Materials that may be moved include explosives, noxious gases, chlorine, and other chemical agents. Each material has its special characteristics, container system, and transport system deemed appropriate for the particular hazardous material.

The TS involves an origin and a destination, and in between it is a network of nodes and links. A node is an element of the transportation network where the material being moved may be stored temporarily, where the carrying vehicle may change, or any other location in the network that does not involve movement using the carrying vehicle. A residence time is associated with each node. A link is an element wherein actual transport takes place. A certain vehicle with an associated average speed is used, and a path length is associated with a link. Population densities are assigned to areas surrounding the nodes and along the link. The inspection procedures followed in the TS are assumed to be known.

The above information, if coupled with atmospheric conditions along the TS (wind velocity, atmospheric dispersion parameters), permits computation of the probability of a release, as well as the consequences of this release at any point in the TS.

The steps of the methodology are as follows:

a. Describe the TS as a network of (storage and transfer) nodes and (transportation) links connecting the origin and end-point of the transport paths considered for the hazardous material system. For example,

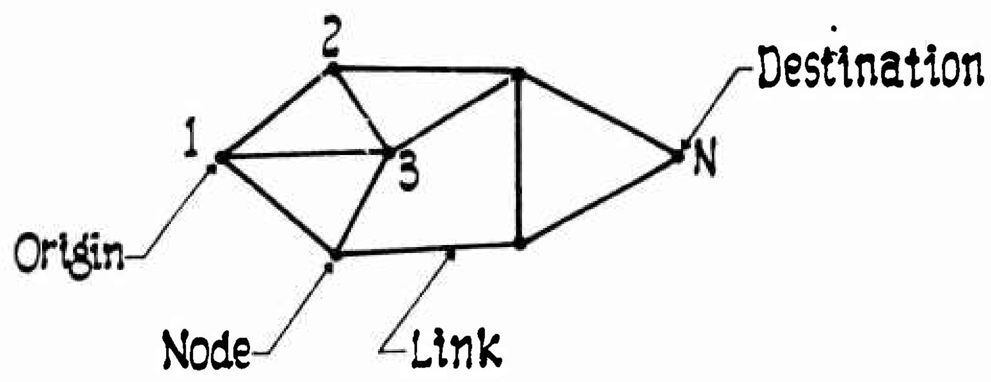


FIGURE 1

SAMPLE TRANSPORTATION NETWORK

b. For each node and link compute

$P(S, Q)$ = probability of release of amount Q at location S. Do this for several standard values of Q. This probability can be modified by the fact that the releases may be detected and terminated along the way.

$N(S, Q)$ = number of casualties from release of amount Q at location S.

$E(S, Q)$ = expected number of casualties from release Q with each container transported through S.

$$E(S, Q) = P(S, Q)\, N(S, Q) \qquad (1)$$

$E(S)$ = expected number of casualties in S with transport of one container of hazardous material through location S. The summation accounts for the release magnitudes considered at discrete levels.

$$E(S) = \sum_{Q} E(S, Q) \qquad (2)$$

c. For every path P through the networ'', compute a risk associated with the path

$R(P)$ = expected number of casualties when path P is followed, where the summation is over all nodes and links S in the path. The value R(P) is a path function which may be used to establish the minimum risk path for a given network.

$$R(P) = \sum_{S \epsilon P} E(S) \qquad (3)$$

d. Compare various alternatives in the transport sequence.

More will be said on the risk function later. It is important to note that other measures of risk can be adapted, each of which can be obtained from the models discussed.

3. PROBABILITY OF RELEASE

3.1 Fault Tree Analysis and Probabilities

The probability of release, P(S, Q), is basically the probability of an undesired event. In the methodology described here, the model used to estimate the P(S, Q) is developed from a fault tree analysis of the transport system. In fault tree analysis*, the first step is to characterize or stipulate the ultimate undesired event, UUE, in this case a release of hazardous materials to the atmosphere. Next, the means by which the UUE can occur is delineated. This is done by stepwise deduction of those elementary events and conditions which, singularly or in combination, can cause a UUE. This deductive logic is displayed graphically as a fault tree which shows the logical relations between basic failure events and the UUE.

The basic failure events are those which have known probability of occurrence. Thus, the next step is to assign appropriate probabilities or failure rates to each basic failure event. Then the fault tree is converted into a set of Boolean statements describing the fault logic existing between basic failure events and the UUE. Using basic failure event probabilities in the Boolean form of the fault logic, the probability of the UUE may be calculated. Since UUE's for most systems involve a rather complex fault logic, calculation of the UUE probability requires a digital computer; and the fault logic statements are typically FORTRAN statements. The computer calculates the probability of the UUE by Monte Carlo simulation of the fault logic to find dominant failure combinations. These combinations are then numerically evaluated using the probabilities or failure rates for the basic failure events. The result is the probability of the UUE.

---

*Fault tree analysis is discussed elsewhere (See Reference 6). Basically, for a specified source strength and a specified element of the network, one computes the probability that there is an amount Q that is released. Thus, one may assume that small values of Q correspond to leaks and so construct the fault tree for small leaks. Large instantaneous releases can be assumed to be those caused by large punctures or by a rupture of the containers, and another fault tree can be drawn for that purpose.

3.2 Basis for Probability Model

In developing the probability model (or fault tree), the transport system is treated as a system of barriers or a barrier model such as that shown in Figure 2. These barriers include physical systems which prevent, impede, or limit the release of material to the atmosphere. The magnitude of the release depends on the original amount of material available, the size of the breach, the type of barriers, and the mechanism of release in the barrier model. Besides serving as a basis for fault tree analysis, the barrier model provides the basis for correlating the probability of release to the effect of the release, as determined by its type and magnitude.

Each type of release has, in theory, a unique probability of occurrence. There can exist many types of releases, depending on magnitude. However, data that is available precludes one from using more than a few types of releases. Three releases which have been used in the model are as follows:

a. Instantaneous release

b. Large continuous release

c. Small continuous release

Three fault trees were drawn corresponding to these three types of releases.

3.3 Numerical Evaluation of Release Probability

The numerical evaluation of the probability of occurrence of the undesired event by simulation is discussed in detail elsewhere.[7]

Each basic failure event, E, has a probability of occurrence, p(E). Suppose p(E) = 0.25. The probability that the event does not occur is denoted by $p(\overline{E})$. Clearly, $p(\overline{E}) = 1 - p(E)$. The occurrence or the nonoccurrence of the event can easily be simulated on the computer by using a random number generator. The random number generator is one which gives numbers uniformly between 0 and 1. To simulate the probability of occurrence of event E, uniform random number r_j is generated where $0 < r_j \leq 1$. If $0 < r_j \leq 0.25$, one may say that the event E occurs; and if $0.25 < r_j \leq 1$, then event E does not occur. Note that one could just as well have picked any interval designation with the proper proportions. For example, if $0 < r_j \leq 0.5$, or $0.75 < r_j \leq 1$, the event E does not occur; and if $0.5 < r_j \leq 0.75$, then E occurs.

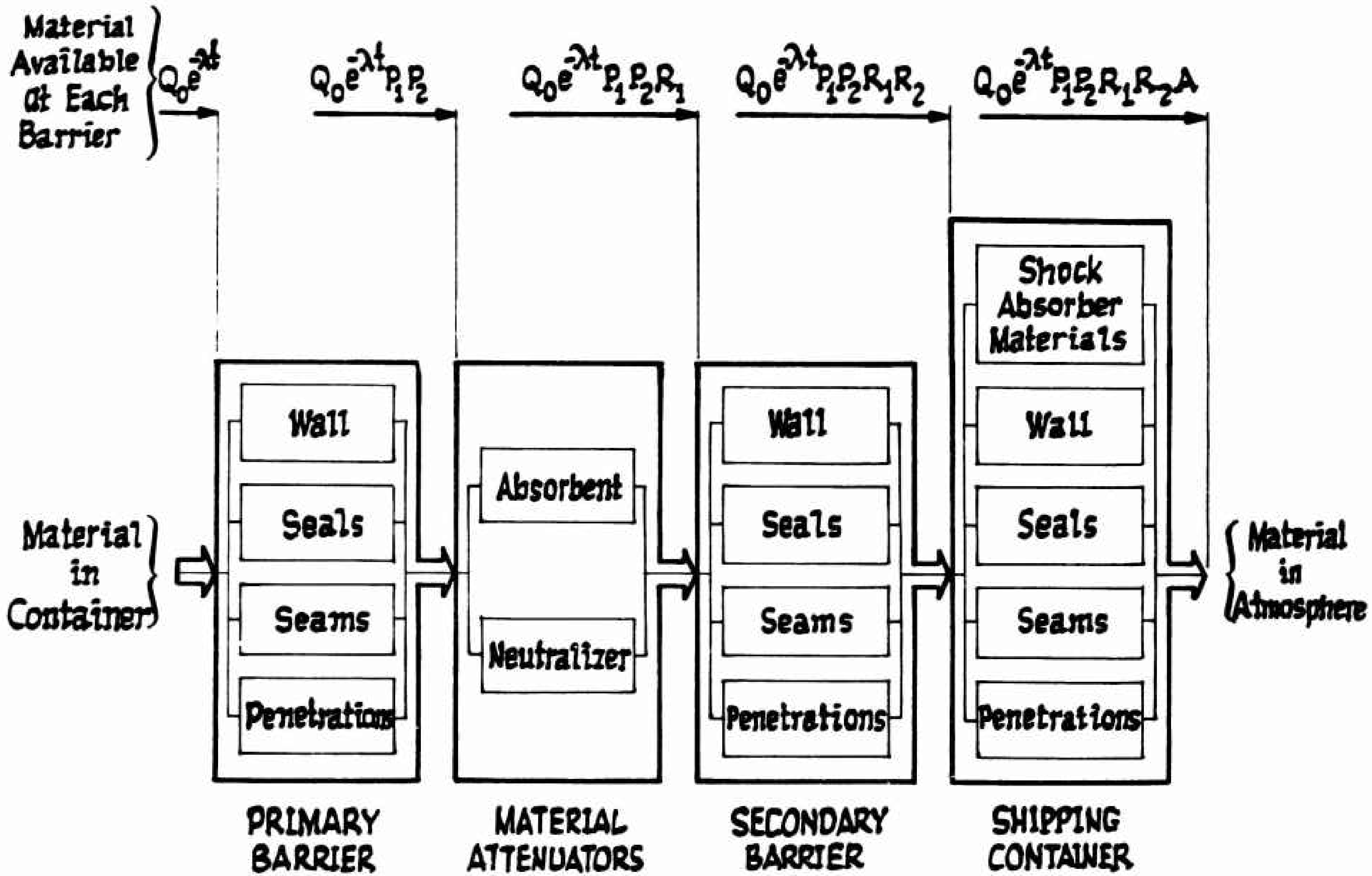


FIGURE 2

GENERALIZED BARRIER MODEL

A similar procedure is applied to all basic components in a system or basic failure events in the undesired event that is being simulated. Thus, if component x_j has probability of failure $p(x_j)$, then the component is considered to be in the failed state if $0 < r_j \le p(x_j)$, and to be unfailed otherwise.

Furthermore, if component j has an exponential failure distribution with mean-time-to-failure θ_j, one could set the failure criterion as follows. By using the same uniform random generator, an r_j is generated and if

$$0 < r_j \le 1 - e^{-t/\theta_j}, \text{ the component fails;}$$

and if

$$1 - e^{-t/\theta_j} < r_j \le 1, \text{ the component does not fail.}$$

The only difficulty with the above procedure, which is a direct simulation technique, is that θ_j is usually large. In most cases, therefore, $p(x_j)$ is very small. Thus, when one is directly simulating the behavior of the components or events, many simulation trials are needed before an event of interest, namely component failure, takes place. To avoid this, biased values of the probability of failure are used during the simulation. This procedure allows one to find quickly those combinations of component failures that lead to the undesired events.

By algebraic techniques, the probability of the undesired event can be calculated once the various dominant failure combinations are known. This approach does not identify all possible failure combinations or modes leading to failure. However, the simulation technique establishes the significant or more probable failure states leading to the undesired event. As already indicated, the undesired event is the release of hazardous substances to the atmosphere. Simulation is carried out for all elements (nodes and links) in the TS.

3.4 Probability of Release Existence

To complete the calculation of the probability of P(S,Q) it is necessary to estimate the probability that release amount Q exists in element S of the TS. In the method described herein, fault tree analysis calculates the probability that Q is initiated in S. Then a leak detection probability is developed to include the possibility that Q was carried over from prior TS elements. The probability that a release exists in a TS element is then calculated, which reflects the fact that it was initiated in that element or it was introduced to that element from

prior TS elements. Normally, if a leak is detected on a previous element of the path, the leak would be fixed or the transport would be terminated. However, there is a distinct possibility that the leak will not be detected immediately. To recognize this possibility, a leak detection probability is assigned to each release magnitude.

The probability of leak detection is considered in the probability of release existence by using the conditional probability theorem. Let P[LDP(Q)] be the probability that release Q will be detected when passing from one element to the next, i.e., the leak detection probability for release Q. Then the probability of release Q existing in element S_i is given by:

$$P(S_i) = P(S_i/S_{i-1})\, P(S_{i-1}) + P(S_i/\bar{S}_{i-1})\, P(\bar{S}_{i-1}) \qquad (4)$$

where

$P(S_i)$ = probability that release Q exists in element S_i.

$P(S_{i-1})$ = probability that release existed in element S_{i-1}.

$P(S_i/S_{i-1})$ = probability that release exists in S_i given that it existed in S_{i-1}.

$$P(S_i/S_{i-1}) = 1 - P(LDP(Q)) \qquad (5)$$

$P(S_i/\bar{S}_{i-1})$ = probability that release Q exists in element S_i given that it did not exist in element S_{i-1}. This is taken to be the probability of release initiation in element S_i as calculated by fault tree analysis.

$$P(\bar{S}_i) = 1 - P(S_i);\; P(\bar{S}_{i-1}) = 1 - P(S_{i-1}) \qquad (6)$$

If it is assumed that the transport container is not releasing any material when introduced to the first TS element, $P(S_0)$ is 0 and $P(S_1)$ is the probability that release Q was initiated in the first element, i.e., the fault tree analysis probability. The larger the release rate, the greater the probability, P [LDP(Q)], for detection in each element of the path.

4. RELEASE EFFECT MODEL

4.1 Measure of Effect

The effect of a release of hazardous materials can be measured in many ways. It may be the expected number of deaths or injuries, the area of land affected or contaminated, or the dollar cost of recovery and cleanup. The measure chosen for illustration in this paper is the number of casualties based on an exponential dose relationship.

To calculate the number of casualties, the amount of material released is estimated and then the area and number of people affected by the release are calculated. This number, N(S, Q), is calculated for each release magnitude in each element or sub-element of the TS having distinctly different population distributions.

4.2 Release Magnitude

Coupled with the release probability is an atmospheric release magnitude, $Q_A(t)$. This release magnitude includes factors for time decay of the material, if any, while in storage. If the material decays at a constant rate λ while in storage, the initial amount Q_o at time t later is decayed to

$$Q(t) = Q_o e^{-\lambda t} \tag{7}$$

In general, the amount of material which can be considered released to the atmosphere is actually much less than the amount Q(t) inside the container at time t. One reason is that the transport containers may be of multiwall design; and thus, the material must pass these various walls before it is released. It may also have to be aerosolized. Furthermore, it may have to pass through various protective attenuators such as absorbents, neutralizers, or chemical reactants. The generalized barrier model used in estimating release probability also serves as a basis for relating the various attenuation factors as shown in Figure 2. From Figure 2 the following expression is suggested for estimating the actual amount of material released to the atmosphere:

$$Q_A(t) = Q(t)\, P_1 P_2 P_3 R_1 R_2 R_3 \ldots R_N \tag{8}$$

where

$Q_A(t)$ = amount of material/unit time released to the atmosphere at time t.

P_1 = fraction of $Q(t)$ available for release from primary wall.

P_2 = fraction of P_1 released per minute.

P_3 = fraction of material released to atmosphere in aerosolized form.

R_i = fraction of material which passes barrier i ($i = 1, 2, 3 \ldots N$).

For the case of an instantaneous release, one might assume unity for all the factors besides P_1 and P_3, so that

$$Q_A(t) = Q(t)\, P_1 P_3 \tag{9}$$

For a continuous release case when the container is being moved, one divides $Q_A(t)$ by the vehicle speed to get the release per unit distance q:

$$q = \frac{Q_A(t)}{V} = \frac{Q(t)\, P_1 P_2 P_3 R_1 R_2 \ldots R_N}{V} \tag{10}$$

4.3 Calculation of Number of Casualties

To calculate $N(S, Q)$ the area within which a specified dosage or concentration range exists at S for release, Q, is first computed. Next, this area is multiplied by the probability of injury within that range. This effective area can then be multiplied by the population density to get the expected number of casualties. The calculation can be carried out for various concentration ranges (corresponding to different distances and times from the source). The model is as follows:

The number of people injured by a release of Q organisms at element S in a TS path is evaluated as

$$N(S, Q) = \rho\,(s, y)\; p\,[D(x, y, Q)]\, dxdy \tag{11}$$

where

$\rho\,(x, y)$ = population density, people/m^2

$D(x, y, Q)$ = dose received by the population at position (x, y) as a result of release Q.

$p\,[D(x, y, Q)]$ = probability of injury with dose D.

In the actual evaluation of N(S, Q), population density is not usually available as a function of x and y. Thus, an average density, p(S), is assigned for regions in the vicinity of nodes and links. In view of this,

$$N(S,Q) = \rho(s) \quad p\,[\,D(s,y,Q)\,]\,dxdy \tag{12}$$

Instead of an evaluating integral in Equation 11, an approximate form is used.

$$\int p\,[D(x,y,Q)\,]\,dxdy \cong \Sigma\, p_i\, A_i \tag{13}$$

where p_i is an infection probability within the area A_i, and A_i is defined as the areas within which the dosage is of such a magnitude that the probability of infection is between p_i and p_{i-1}. If D_i denotes the dosage required to produce infection probability p_i, and $A(D_i)$ denotes the area receiving dose D_i or greater, then

$$A_i = A(D_i) - A(D_{i-1}). \tag{14}$$

The numbers $A(D_i)$ are computed from the expression

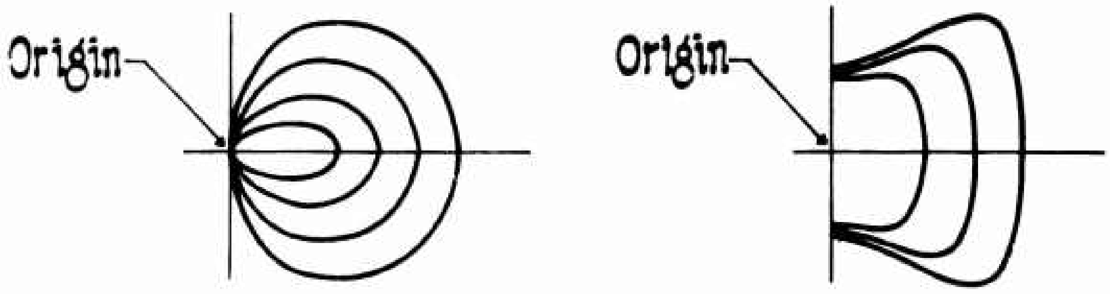
$$A(D_i) = \int_0^{x_m} y(x)\,dx \tag{15}$$

where

$A(D_i)$	=	area within which a dose of D_i or greater will occur.
x_m	=	maximum downwind distance at which D_i occurs.
$y(x)$	=	contour function for D_i determined by the source strength, material physical characteristics, and atmospheric diffusion formula for the source configuration.

4.4 Dose Equations and Areas Infected

One can take the various formulas for dose and compute the contour y(x) as shown in Figure 3. These dose equations are well known and readily available. See, for example, Reference 4. In the equations



(a) Point Sources (b) Line Sources

FIGURE 3

DOSE CONTOUR LINES

that follow, α and β are temperature-dependent parameters of the diffusion conditions. That is, it is assumed that the diffusion standard deviations are described by simple power laws, relative to a standard distance x_1, used for measurement of σ_y and σ_z. The decay rate of the material after it is released to the atmosphere is given by K, and u is the wind speed in the x direction. The basic form of the dose equation is $D = f(Q, x, y, z, t)$ for which one can set $z = o$ and get various forms depending upon the model used.

For the instantaneous release model, one has

$$1 = \frac{a}{\left(\frac{x}{x_1}\right)^{\alpha+\beta}} \exp \frac{-y^2}{2\sigma_y^2 (x_1) \left(\frac{x}{x_1}\right)^{2\alpha}} \exp \left(\frac{-kx}{u}\right), \tag{16}$$

where

$$a = \frac{Q}{Du} \cdot \frac{1}{\pi \sigma_y (x_1)\, \sigma_z (x_1)} . \tag{17}$$

For the continuous fixed release model, the dose equation gives

$$1 = at \exp \frac{-y^2}{2\sigma_y^2 (x_1) \left(\frac{x}{x_1}\right)^{2\alpha}} \exp \left(\frac{-kx}{u}\right) \tag{18}$$

where t is the time after release starts.

$$a = \frac{Q}{Du} \cdot \frac{1}{\pi \sigma_y (x_1) \sigma_z (x_1)} \tag{19}$$

Other equations for the dose contour are available in the model. Most of these, similar to Equations 14 and 19, are well known. These equations are solved numerically for y(x) by using a modified form of the Newton-Raphson method. This procedure is given in Reference 5. The areas are then calculated for the various dose contours. Finally, probability of infection is used to weight the area computed for each dose level.

5. A HYPOTHETICAL CASE

Using the preceding model, a computerized evaluation of risk in transport of a hypothetical weapon system has been performed. The transport sequence network is shown in Figure 4.

5.1 Basis and Cases Studied

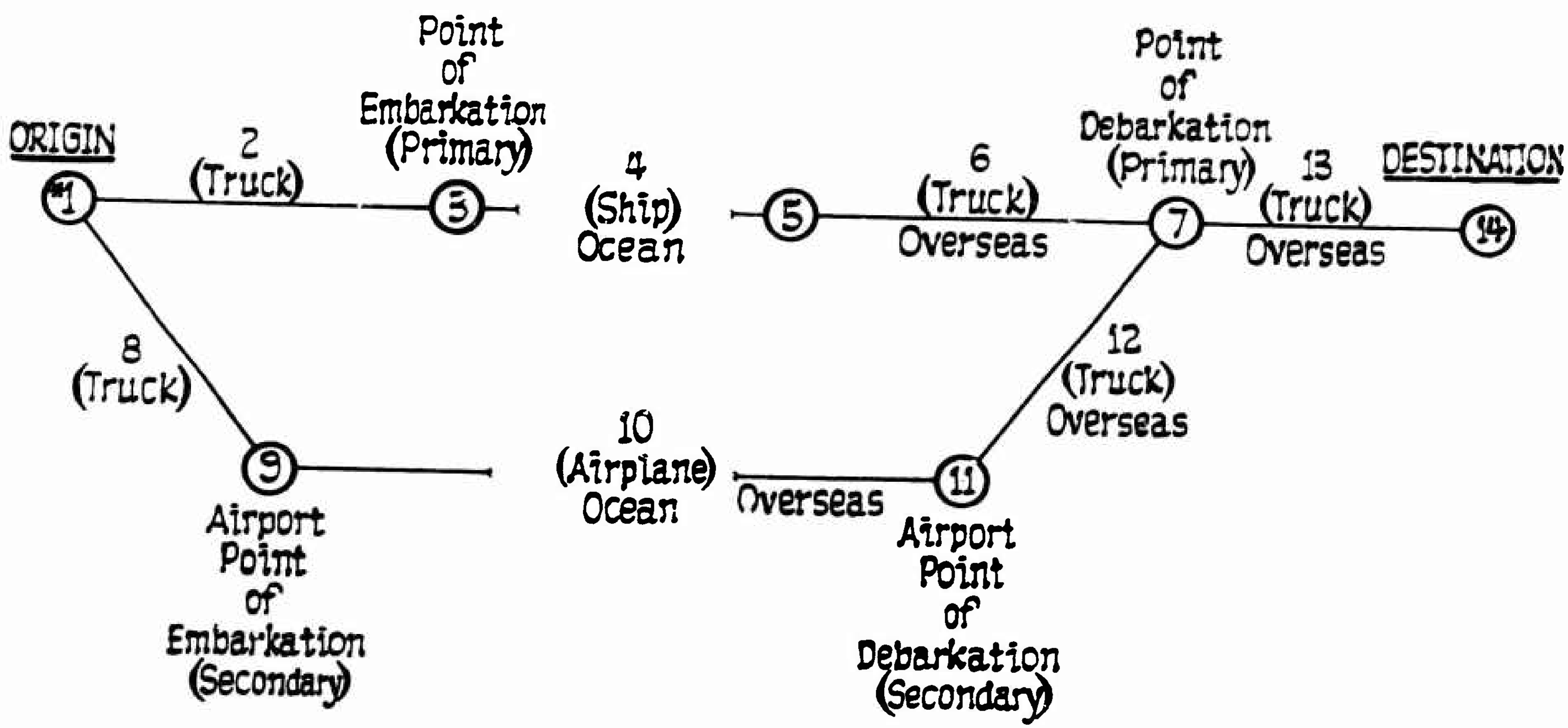
This evaluation assesses the risk on two alternate hypothetical TS paths between the origin (weapon assembly point) and the destination or use point. Briefly, these cases may be summarized as follows:

Case 1 - Standard Case. This case uses a set of parameters considered typical of a normal weapon - TS configuration. It serves as a standard for comparison with the remaining cases.

Case 2 - Expedited Delivery. This case uses the same parameters as Case 1 except that the storage times at most of the nodes have been reduced to minimize the time the weapon is in the TS.

Case 3 - Changed Material. This case uses the same parameters as Case 1 with the exception that material properties have been altered to simulate use of a different material (decreased physiological effect and decreased storage decay rate).

Case 4 - Changed Container. This case uses the same parameters as Case 1 with the exception that certain fault tree input data has been changed to reflect an assumption



*Numbers Indicate TS Element I.D. Numbers

FIGURE 4

SCHEMATIC OF HYPOTHETICAL TS

that the shipping container is designed to assure survival of the weapon casing with impact velocities of up to 400 fps. This change is effected by lowering the probabilities for the conditional event that the impact loads exceed 50 g.

Data was gathered on the hypothetical path. Table 1 indicates part of the information that is needed for the various elements of the network. Table 2 gives the parameters for the barrier models used.

5.2 Results for Hypothetical Case

Summary results are given in Figure 4 and in Tables 3 and 4. These outputs or results are specific to the hypothetical weapon TS configuration.

Table 3 presents a summary of risk, probability, and area values determined for each TS path and each case in this analysis. These data show that minimum risk, 2.75×10^{-10} casualties per trip, would be achieved when transporting the agent in the improved shipping container via the shipboard route (TS Path 1). Maximum risk, 1.38×10^{-5} casualties per trip would occur with expedited delivery via the air route (TS Path 2). The maximum risk is approximately 50,000 times greater than the minimum. With regard to the standard case (Case 1), the minimum risk case is 4,000 times better (less risky) on the same TS path.

If the Case TS path combinations listed in Table 4 were all that were considered, it would be recommended that the Case 4-Path 1 combination be used. If Case 4 were excluded from the alternative choices, then it would be recommended that use of the less harmful material (Case 3) on either TS path would be the preferred combination.

It is interesting to note that when selecting case parameters for analysis, it was expected that Case 2 (expedited delivery) would represent a low risk situation. The length of residence time at the nodes had been significantly reduced to give a reduced chance for exposure. Results of the analysis show that this case gives the highest risk on both paths. The reason for this unexpected result is that the material storage decay rate is short compared to the normal delivery time. Thus, by expediting delivery, the inventory of hazardous material was increased at later stages (higher population densities) in the TS paths.

In addition to identifying minimum risk case-path combinations, it is possible to examine the contributions of various TS path elements to risk, release probability, and release effect. Looking at risk

TABLE 1

TS POPULATION DATA

TS Element I. D. No.	Location Name	Location Type[1]	Path[2] Length Mi.	Population Data[3]: Total[4] on Vehicle	Population Data: Density People(sq mi) On Site	Population Data: Density People(sq mi) General Public
1	Origin	N	-	-	1,300	3,900
2	City 1	UA	3	2	-	2,130
	City 1 to City 2	R	150	2	-	31
	City 2	UA	2	2	-	2,000
	City 2 to City 3	R	60	2	-	25
	City 3	UA	2	2	-	3,310
	City 3 to City 4	R	83	2	-	35
	City 4	UA	2	2	-	3,000
	City 4 to City 5	R	1	2	-	100
	City 5	UA	6	2	-	3,930
	City 5 to City 6	R	[illegible]	[illegible]	[illegible]	45
	City 6	UA	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	Seaport [illegible]	N	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible] City 18	R	[illegible]	2	-	[illegible]
	[illegible]	UA	9	2	-	7,850
	City 19	UA	15	2	-	15,900
7	TOD	N	-	-	-	15,900
13	City 20	UA	9	2	-	11,050
	City 20	UA	5	2	-	13,210
	City 20 to City 21	R	10	2	-	420
	City 21	UA	4	2	-	17,220
	City 21 to City 22	R	51	2	-	300
	City 22	UA	3	2	-	7,350
	City 22 to City 23	R	35	2	-	290
	City 23	UA	7	2	-	8,220
14	SASP	N	-	-	-	8,220

(1) Location types are node (N), urban agglomeration (UA), rural (R), and high seas (HS).

(2) Path length is required for all nonnode locations. Enter zero if location type is node.

(3) When transporting, specify only on-vehicle and general public data. When at a node, specify only on-site and general public data.

(4) On-vehicle data should indicate total number of personnel on vehicle.

TABLE 2

SUMMARY OF BARRIER MODEL FACTORS FOR EXAMPLE APPLICATION

Factor	RELEASE TYPE		
	Type 1	Type 2	Type 3
	Instantaneous	Large Continuous	Small Continuous
P_2, %/min	100.0	50.0	10.0
R_1, %	100.0	20.0	5.0
R_2, %	100.0	50.0	1.0
R_3, %	100.0	50.0	50.0
P_3 (Cases 1, 2, and 4), %	0.001	0.001	0.1
P_3 (Case 3), %	0.0003	0.0003	0.03

TABLE 3

SUMMARY OF PATH VALUES FOR ALL CASES

Case	Path 1	Path 2
CASE 1-NORMAL DELIVERY		
Probability	5.62×10^{-5}	7.45×10^{-5}
Area Infected, m^2	$1.23 \times 10^{+3}$	9.41×10^{2}
Risk, People Infected/Trip	1.33×10^{-6}	1.37×10^{-6}
CASE 2-EXPEDITLD DELIVERY		
Probability	5.61×10^{-5}	7.44×10^{-5}
Area Infected, m^2	3.02×10^{3}	2.27×10^{3}
Risk, People Infected/Trip	4.07×10^{-6}	1.38×10^{-5}
CASE 3-NORMAL DELIVERY-CHANGED AGENT		
Probability	5.62×10^{-5}	7.45×10^{-5}
Area Infected, m^2	1.51×10^{2}	6.95×10^{1}
Risk, People Infected/Trip	1.32×10^{-7}	5.16×10^{-7}
CASE 4-NORMAL DELIVERY-CHANGED CONTAINER		
Probability	8.01×10^{-8}	6.00×10^{-6}
Area Infected, m^2	1.23×10^{3}	9.41×10^{2}
Risk, People Infected/Trip	2.75×10^{-10}	2.81×10^{-8}

TABLE 4

SUMMARY OF RISK* CONTRIBUTIONS

Rank of Element	Case 1 Normal Delivery: Path Element I. D. No.	Case 1 Normal Delivery: Total Risk for Element	Case 2 Expedited Delivery: Path Element I. D. No.	Case 2 Expedited Delivery: Total Risk for Element	Case 3 Changed Agent: Path Element I. D. No.	Case 3 Changed Agent: Total Risk for Element	Case 4 Changed Container: Path Element I. D. No.	Case 4 Changed Container: Total Risk for Element
PATH 1								
1	2	1.21×10^{-6}	2	2.66×10^{-6}	6	6.95×10^{-8}	4	2.29×10^{-10}
2	6	9.01×10^{-8}	6	1.24×10^{-6}	2	5.72×10^{-8}	3	2.17×10^{-11}
3	4	1.85×10^{-8}	4	9.63×10^{-8}	4	3.17×10^{-9}	2	2.08×10^{-11}
4	1	5.07×10^{-9}	13	7.24×10^{-8}	13	2.11×10^{-9}	6	2.68×10^{-12}
5	3	1.08×10^{-10}	1	3.75×10^{-9}	1	1.42×10^{-10}	5	1.07×10^{-12}
6	13	2.46×10^{-11}	3	2.10×10^{-10}	7	9.95×10^{-12}	7	2.46×10^{-13}
7	5	5.37×10^{-12}	14	2.85×10^{-11}	3	9.22×10^{-12}	1	1.32×10^{-14}
8	7	1.23×10^{-12}	5	2.61×10^{-11}	5	1.94×10^{-12}	13	3.90×10^{-15}
9	14	8.86×10^{-16}	7	1.92×10^{-11}	14	1.37×10^{-12}	14	1.77×10^{-16}
TOTAL (All Elements)		1.33×10^{-6}		4.07×10^{-6}		1.32×10^{-7}		2.75×10^{-10}
PATH 2								
1	12	1.17×10^{-6}	12	1.26×10^{-5}	12	4.85×10^{-7}	10	2.81×10^{-8}
2	10	1.97×10^{-7}	10	9.55×10^{-7}	10	2.70×10^{-8}	12	1.01×10^{-11}
3	1	5.07×10^{-9}	13	2.26×10^{-7}	13	3.52×10^{-9}	7	8.46×10^{-13}
4	8	1.78×10^{-9}	8	3.90×10^{-9}	1	1.42×10^{-10}	9	2.31×10^{-13}
5	13	1.15×10^{-10}	1	3.75×10^{-9}	8	8.36×10^{-11}	8	3.00×10^{-14}
6	7	4.23×10^{-12}	14	1.12×10^{-10}	7	1.50×10^{-11}	1	1.32×10^{-14}
7	9	1.51×10^{-12}	7	4.78×10^{-11}	14	2.53×10^{-12}	13	1.18×10^{-14}
8	11	8.57×10^{-13}	11	6.19×10^{-12}	11	2.04×10^{-13}	14	1.13×10^{-15}
9	14	5.63×10^{-15}	9	3.75×10^{-12}	9	9.21×10^{-14}	11	8.83×10^{-16}
TOTAL (All Elements)		1.37×10^{-6}		1.38×10^{-5}		5.16×10^{-7}		2.81×10^{-8}

* Risk = Number of Infections/Weapon Trip Through Element

contributions in Table 4, it appears that the predominant sources of risk in either TS path derive from truck transportation through populated areas.

Another view of the risk contributions from various elements in Path 1 is shown in Figure 5. In this figure the cumulative risk is plotted as a function of location in TS path for all four cases. Sharp inflections in the risk curve indicate the major contributors to risk. Perhaps the most important information deriving from these curves is that the level and location of risk calculated by the methodology is quite responsive to changes in the material-weapon-TS configuration.

Added insight into the sources of risk is given by considering the relation between release type and risk. Results of this hypothetical analysis show that the instantaneous release is the dominant source of risk. Both the probability and effect of instantaneous release are large in all TS path elements relative to other release types, except when using a more crashworthy container (Case 4). In Case 4, the probability of instantaneous release is considerably below that for continuous releases; these latter releases are, therefore, the dominant contributors to risk.

The probability of release for each release type remains relatively constant for all elements of the TS. To identify ways of reducing these probabilities, the computer output was examined to identify predominant failure combinations; i.e., combinations whose probability of occurrence falls in the largest order of magnitude of the reported failure combination probabilities. One failure combination was found to exclusively determine the probability of instantaneous release. The inputs in this combination relate to the occurrence of accidents in which the impact load exceeds 50 g. Thus, to minimize the probability of instantaneous release in this hypothetical example, design efforts should be focused primarily on development of a more crashworthy weapon-system shipping-container configuration.

6. CONCLUSIONS

The preceding results have identified:

a. A minimum risk material-weapon system-TS path configuration; i.e., Case 4 and Path 1.

b. A minimum risk TS path for each material-weapon system configuration.

c. The contribution to risk by each element in each TS path.

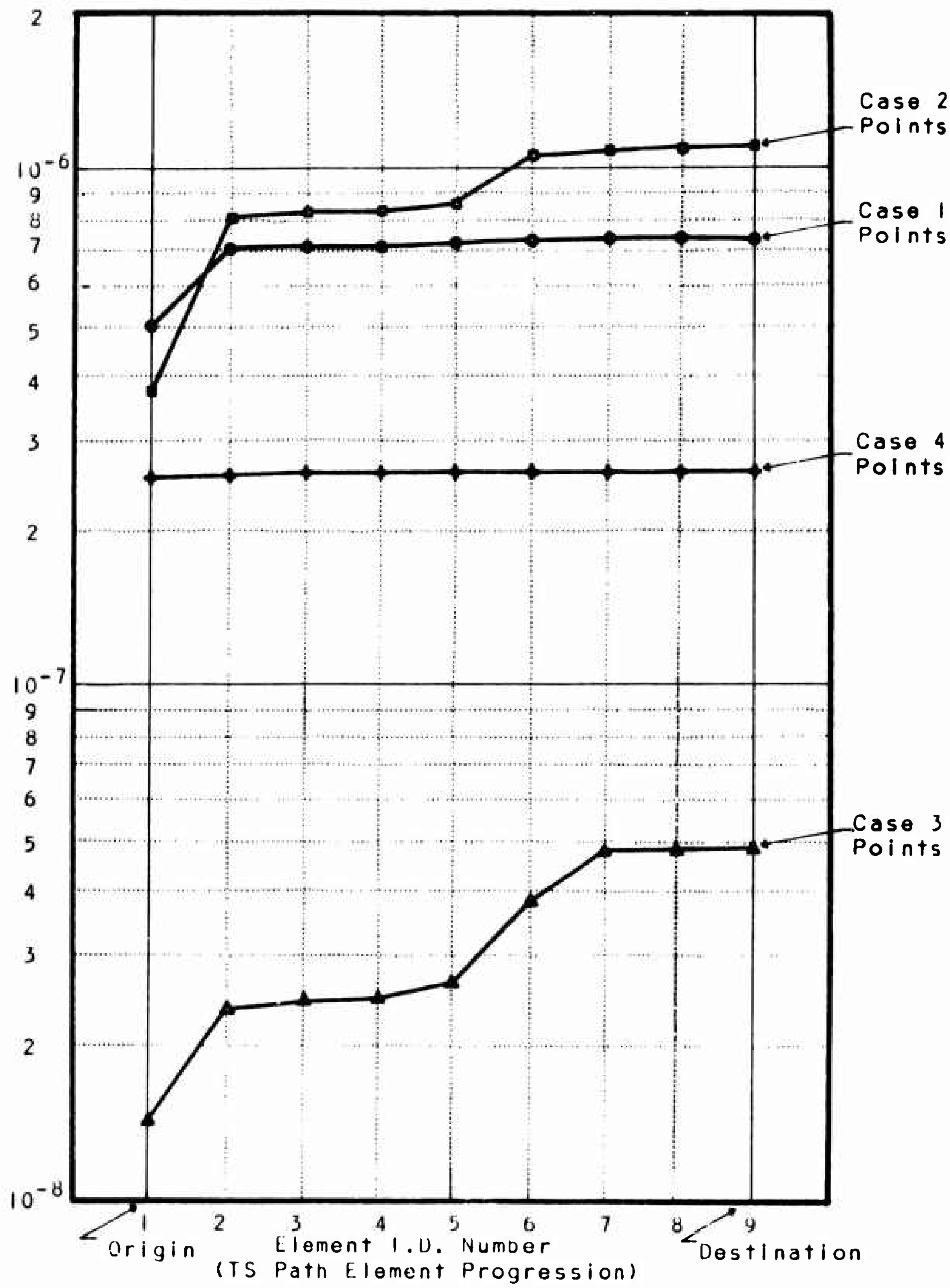


FIGURE 5

CUMULATIVE RISK VERSUS LOCATION IN TS PATH

d. The relation between probability and effect in determining risk for each element.

e. The elements in which the probability of release is highest.

f. The release types contributing most to risk; e.g., instantaneous in Cases 1, 2, and 3 and continuous in Case 4.

g. TS activities and design factors most strongly affecting risk and the probability of release in each element; e.g., transport accidents and crashworthiness of the weapon-shipping container configuration.

Other types of comparative analyses may also be developed from the HAZTRANS output depending on the analyst's interest.

Two major conclusions can be derived from the results in this hypothetical application. First, changes in material-weapon system-TS path condigurations can lead to changes in risk which may not be anticipated by qualitative judgment, but will be identified by the methodology in a quantitative manner. Second, the methodology is flexible and responsive to the factors which determine risk in hazardous material transport. It provides data which can be used to arrive at minimum risk solutions in both the logistics and design.

As a final comment, it is believed that a practical method has been developed for "a priori" estimates of risk in the transport of hazardous materials. The model discussed in this paper admittedly has limited capability at this time, yet it can yield useful results in its present form. Increasing accuracy and realism in the model and its results are well within the grasp of present system safety analysis technology. The major requirement is a commitment to further refinement of the existing models and development of data suitable to these models, especially probability data.

7. REFERENCES

1. Howerton, A. E. "Estimating Area Affected by Chlorine Release," Symposium on Loss Prevention in the Process Industries - Part III. 64th National AIChE Meeting, March 1969.

2. Turner, W. D., S. V. Kaye, and P. S. Ronwer, "EXREM and INREM Computer Codes for Estimating Radiation Doses to Population from Construction of a Sea Level Canal with Nuclear Explosives," K-1752, Union Carbide Corporation, September 1968.

3. Smith, M., Ed., "Recommended Guide for the Prediction of the Dispersion of Airborne Effluents," ASME Committee on Air Pollution Controls, May 1968.

4. Milly, G. H., "Atmospheric Diffusion and Aerosolized Munitions Expenditures," U. S. Army Chemical Corps, ORG Study 17, May 1958.

5. Garrick, B. J., et al, "A Risk Model for the Transport of Hazardous Materials," Holmes & Narver, Inc., June 1969.

6. Fentz, P. J., and T. A. Waldeck, "The Application of Fault Tree Analysis to Dynamic Systems," The Boeing Company, June 1955.

7. Baldenado, O. C., "On Some Computer Methods for System Reliability Evaluation," International Conference on Quality Control, Tokyo, Japan, October [illegible].

POSSIBLE SOLUTIONS TO ENVIRONMENTAL POLLUTION
ASSOCIATED WITH DESTRUCTION OF AMMUNITION AND EXPLOSIVES

Moderator:

Pope Lawrence
National Air Pollution Control
Department of Health, Education & Welfare
Washington, D.C.

POSSIBLE SOLUTIONS TO ENVIRONMENTAL PROBLEMS ASSOCIATED WITH DESTRUCTION OF AMMUNITION AND EXPLOSIVES

MODERATOR'S SUMMARY

Increasing public pressure accompanied by Federal legislation and Executive Orders to eliminate environmental pollution has spurred intensive search within the Federal agencies for alternatives to traditional practices, such as open air destruction or dumping of explosives wastes at sea. Examples of innovate thought and action to find feasible solutions to particular problems were presented at this seminar in five talks, each of which stimulated substantial audience participation.

An electrolytic method for recovery of metallic lead from an alkaline solution of bulk quantities of lead azide was described by Mr. J.B. Polson of Mason and Hanger - Silas Mason Co. His method, now being tested out in pilot plant, appears to be a highly attractive alternative to explosion in open air. As described in the formal paper attached to this summary, the method is inexpensive, it yields only nitrogen gas and reusable lead, and it appears to be a solution to a vexing air pollution problem.

In an illustrated talk entitled "Explosive and Propellant Waste Disposal with a View Toward Total Pollution Abatement", Mr. Irving Forsten of Picatinny Arsenal contrasted past practices for TNT waste disposal with new anti-pollution concepts embodied in the Army's program for extensive modernization of its munitions plants. A key element in Mr. Forsten's program is an existing prototype incineration system planned for modification at Picatinny to permit detailed in-house study and evaluation of new disposal methods. The modified facility will contain well instrumented scrubbers, afterburners, catalytic units and controls making possible selection of appropriate design techniques for complete reduction of gaseous combustion products to innocuous forms such as nitrogen and carbon dioxide.

Mr. Herbert Roylance outlined a stimulating program designed to identify and solve environmental pollution problems faced by the Naval Ordnance Systems Command. A new NAVORD Environmental Health Center has been established at Cincinnati, Ohio, and a substantial research and development program is underway with strong direction to reclaim or recycle useful products. Examples of problems under study are:

1. Disposal of explosives and propellants by methods other than by open burning. The methods utilize principles of chemical destruction, controlled incineration, and, in the case of TNT, biological degradation by a micro-organism known to exist but yet to be identified. The University of Indiana is assisting in the search for identification of the "red molecule" degrading organism, and the mechanism by which it degrades TNT, as well as optimum conditions for promoting its action.

   The Naval Ordnance Station at Indian Head, Maryland, and the Naval Weapons Laboratory at Dahlgren, Virginia, are working to improve incineration techniques for ship-board destruction of mono propellants and other waste material.

2. Other studies resulting in elimination of air pollution sources include recovery not only of silver from photographic film emulsions but also recovery of the film itself. Another study produced a method for converting wooden sheathing and dunnage to a product useful in chip-board manufacture. This process has eliminated trouble-some smoke formerly discharged by bee-hive incinerators on San Francisco Bay.

3. Methods to reduce "noise pollution" caused by detonation of explosives are under investigation at the Naval Ordnance Laboratory Test Facility at Solomon's Island, Maryland.

Mr. Emil Christofano of Hercules Corporation discussed "Motivation for Industrial Involvement in Recovery and Recycle of Wastes". Pointing out that recycling is nature's way of handling waste materials, Mr. Christofano cited examples of economic benefits resulting from production of industrial chemicals from a variety of originally unwanted materials such as pine stumps, cotton linters, surplus nitrocellulose (converted to dynamite), and even municipal refuse and garbage. He said that the fundamental and most powerful incentive to corporate pursuit of aggressive waste recovery policy lies in the opportunity to make a profit.

Mr. Richard Gott, also of Hercules, discussed the scope of problems involving safe disposal of the products of munitions manufacture. Munitions makers today, he said, are employing advanced technology to reduce environmental impact of production losses of materials which range up to 10% of manufactured product. Mr. Gott's broad analysis, based on questions as to what, where, when, how much, etc., brought to focus the fact that all explosives and propellants produced are intended to be fired primarily in the open air in the case of war. If not used in that way, then shelf life and other factors require that millions of tons must eventually be disposed of within finite time limits. Mr. Gott felt that some open burning was necessary - but that it could be controlled. He emphasized the urgent need to include safe, non-polluting disposal techniques in original design plans for all munitions - especially new ones. He called for realistic standards defining environmental quality, as well as for procurement policies under which available industrial technology could be profitably applied to reclaim, salvage, detoxify, or otherwise destroy large stocks of surplus explosive materials without further environmental contamination.

Pope A. Lawrence

Pope A. Lawrence
Scientist Director, P.H.S.
Moderator

BLANK PAGE

DEVELOPMENT DEPARTMENT
MANUFACTURING "B"
BURLINGTON AEC PLANT

A NEW POLLUTION-FREE METHOD OF LEAD AZIDE DISPOSAL

TECHNICAL REPORT
NO. 191
REVISION I

18 SEPTEMBER 1970

Author: T. W. Stull and R. E. Stouder

Laboratory work by: T. W. Stull and R. E. Stouder

Department Head: J. R. Polson

I. INTRODUCTION

This proposal presents a significantly new method for disposal of lead azide. An electrolytic process is used to convert the lead azide to metallic lead and free nitrogen. The advantages are substantial in reduced costs, improved safety and the elimination of pollutant waste materials. Operation is extremely simple in that an operator merely deposits the lead azide in a tank of sodium hydroxide solution and periodically removes lead as a solid similar to the processes used in the recovery of silver from photographic solutions.

This work is being published as preliminary data so that the information may be disseminated as early as possible to interested agencies of the U. S. Government concerned with lead azide operations and disposal.

II. DISCUSSION

The method proposed utilizes an electrolytic process which is applicable for all installations. Lead is.collected on the cathode and nitrogen is evolved at the anode. Electrolysis has added advantages in that the chemical cost is very low, a single solution may be reused many times, and a saleable product may be obtained. A cost comparison with several chemical "Kill Methods" is given in Table 1. Many possible electrolytic solutions were investigated including sodium chloride, sodium chloride acidified with hydrochloric acid, sodium chloride/sodium cyanide,

acetic acid, and sodium hydroxide. A discussion of all the unsatisfactory combinations is not included in this report. The most promising solution used to date is sodium hydroxide. Various concentrations were tested to obtain optimum plating conditions for obtaining a good adherent high density lead deposit. Table No. 2 displays the results of this testing and ten percent sodium hydroxide is presently considered optimum. If the density of lead as recovered is not a factor, then the twenty percent solution is the most efficient tested as of this writing.

Test Procedures

1. Recycling Study

A known amount of lead azide was placed in a beaker containing a ten per cent sodium hydroxide solution. Insoluble metal electrodes were immersed at opposite sides of the beaker and five volts were applied to the electrodes resulting in a current of 1.44 amperes (amps.). With a cathode area of 3.5 square inches this gave a current density of 0.4 amps. per square inch. When the lead azide was partially dissolved, samples of the solution were taken for determination of lead and azide ion concentrations. Lead content was determined using an atomic absorption spectophotometer and azide ion levels were found utilizing the infrared spectrophotometer. Samples of the electrolytic solution were taken at approximately 15 minute intervals until the lead concentration dropped below 1000 parts per million (ppm) level. At this time in the process an additional increment of lead azide was added. This process and analysis were repeated for a total of three cycles. After three such cycles the electrolysis solution was clear and contained only a very small amount of metallic lead which had fallen from the cathode. Data denoting sampling times,

the pH of the solution, and the levels of lead and azide ions are detailed in Table 3. From this data graphs were constructed for each cycle which are displayed in Figures 1 through 3.

Table 4 details the theoretical amount of lead added on each cycle, the single cycle recovery percentages, and the final lead distribution data.

2. Gas Evolution and Lead Distribution

Separate, single cycles were used in determining gas evolution and lead distribution in the electrolytic procedure. Analysis of gases evolved from both the cathode and anode during electrolysis was accomplished by devising a collection apparatus and examining these samples with a mass spectrometer. The collection apparatus used and results of this testing are given in Figure 4.

Work is continuing on addition agent chemicals for use in the plating solution. To date, additives tested have made no significant improvement in the process. Progress has been made in obtaining a firm adhering lead deposit on the cathode by lowering current densities and proper electrode placement.

Metals used as electrodes include platinum, stainless steel, copper and lead. Present indications are that a lead cathode and a stainless steel anode will be the most practical. Further testing will be done to determine the gases evolved from the electrodes when materials other than platinum are used.

III. CONCLUSIONS

The electrolytic method for the disposal of lead azide is practical, efficient, safe, economical, and pollution free. Preliminary equipment costs for an installation capable of processing approximately 50 pounds of lead azide per hour is placed at about $2,500.00. Immediate future work will determine the most desirable current density and voltage and will also include the design of a typical installation. Concurrently a pilot-scale operation is being set up and all aspects fastidiously re-examined to assure that no details have been overlooked that could detract from the apparent advantages of this method.

TABLE 1. Cost Comparison of Various Methods Used for "Killing" Lead Azide

	METHOD	COST/POUND
1.	Sodium hydroxide	\$ 0.23
2.	Ammonium acetate-sodium bichromate	\$15.89
3.	Sodium nitrite-nitric acid	\$ 7.26
4.	Sodium nitrite-acetic acid	\$ 7.26
5.	Ceric ammonium nitrate	\$68.10
6.	Ammonium acetate-sodium nitrate-acetic acid	\$25.42
7.	Electrolysis	\$ 0.02

I. TEST CONDITIONS

Temperature of Solution	82°C ± 2°
Voltage Applied	1.5 volts
Current	Constant
Time of Plating	1 1/2 hours
Anode Material	Stainless Steel
Cathode Material	Copper (Copper was used to facilitate examination of the type of lead obtained)

Solution Concentration	Wt of Lead Azide Added as Pb (gms)	Wt Lead Recovered on Cathode (gms)	Percent Lead Recovery	Lead Type on Cathode	Anode Appearance
2	1.6521	0.4283	25.9	Sponge & Hard	Black Deposit
5	1.2508	0.2426	19.4	Hard	Dark Red Deposit
10	1.4222	0.3529	24.8	Hard	No Deposit
20	1.2876	0.6950	54.0	Hard & Sponge	No Deposit

TABLE NO. 2 EFFECT OF SODIUM HYDROXIDE CONCENTRATION ON TYPE AND AMOUNT OF LEAD DEPOSITS ON CATHODE AND ANODE APPEARANCE.

I. Initial Conditions

Solution - 200 ml. of 10 per cent sodium hydroxide

Electrode material - Platinum

Lead Azide added - 5.7552 gms

Electrolytic conditions - 5.0 volts, 1.4 amperes

II. Cycle Information

Cycle No. 1

Time (min)	Pb (ppm.)	% NaN_3	pH
0	10,000	1.95	13.20
15	4,500	1.57	13.05
30	3,250	1.35	13.20
45	2,250	0.80	13.20
60	2,250	1.05	13.10
99	875	0.25	13.20
Cycle No. 2 4.6041 gms lead azide added; 3.2633 gms lead recovered			
99	4,088	0.25	13.10
114	3,438	1.00	13.10
129	2,812	0.75	13.10
144	1,838	0.83	13.10
178	437	0.70	13.10
203	250	0.65	13.10

TABLE 3. ANALYSIS DATA OF LEAD AND AZIDE ION CONCENTRATION

Cycle No. 3 4.8486 gms lead azide added; 3.1432 gms lead recovered

Time (min)	Pb (ppm.)	%NaN_3	pH
203	2,212	1.60	13.20
218	3,288	0.40	13.20
252	1,088	0.95	13.30
267	838	0.53	13.30
304	288	0.70	13.30
347	250	0.45	13.25

End of cycling 3.0342 gms lead recovered

TABLE 3. ANALYSIS DATA OF LEAD AND AZIDE ION CONCENTRATION (cont.)

I. LEAD FROM CATHODE

	Lead azide added to 200 ml. solution (gm)	Calculated additions as lead (gm)	Electrolysis time at 5 V, 1.44 amps (min)	Solid lead recov. from cathode (gm)	Per cent lead in sol. recovered
C le No. 1	5.7552	4.0942	99	3.2633	79.7
Cycle No. 2	4.6041	3.2754	104	3.1432	76.5
Cycle No. 3	4.8486	3.4493	145	3.0340	68.8
Totals	15.2079	10.8189	348	9.4405	87.3

$$\% \text{ Recovery on Cathode} = \frac{9.4405}{10.8189} \times 100 = 87.3$$

II. LEAD REMAINING IN 200 ml. SOLUTION

	ppm. remaining in solution after run	Wt. Pb in solution calculated from ppm (gm)	% of Lead remaining in solution
Cycle No. 1	875	0.1750	4.27
Cycle No. 2	220	0.0440	0.60
Cycle No. 3	220	0.0440	0.41

$$\% \text{ Lead remaining in solution} = \frac{0.0440}{10.8189} \times 100 = 0.41$$

TABLE 4. RECOVERY OF LEAD IN ELECTROLYSIS OF LEAD AZIDE

LEAD LOCATION	WT. (gms.)
Fluxed Lead Globule	2.0096
Lead Remaining in Flux Solution	0.4534
Lead Remaining in Electrolysis Solution	0.0500
Lead Remaining on Cathode	0.0240
Lead in crucible from Flux filtration	0.0226
Total Lead	2.5596

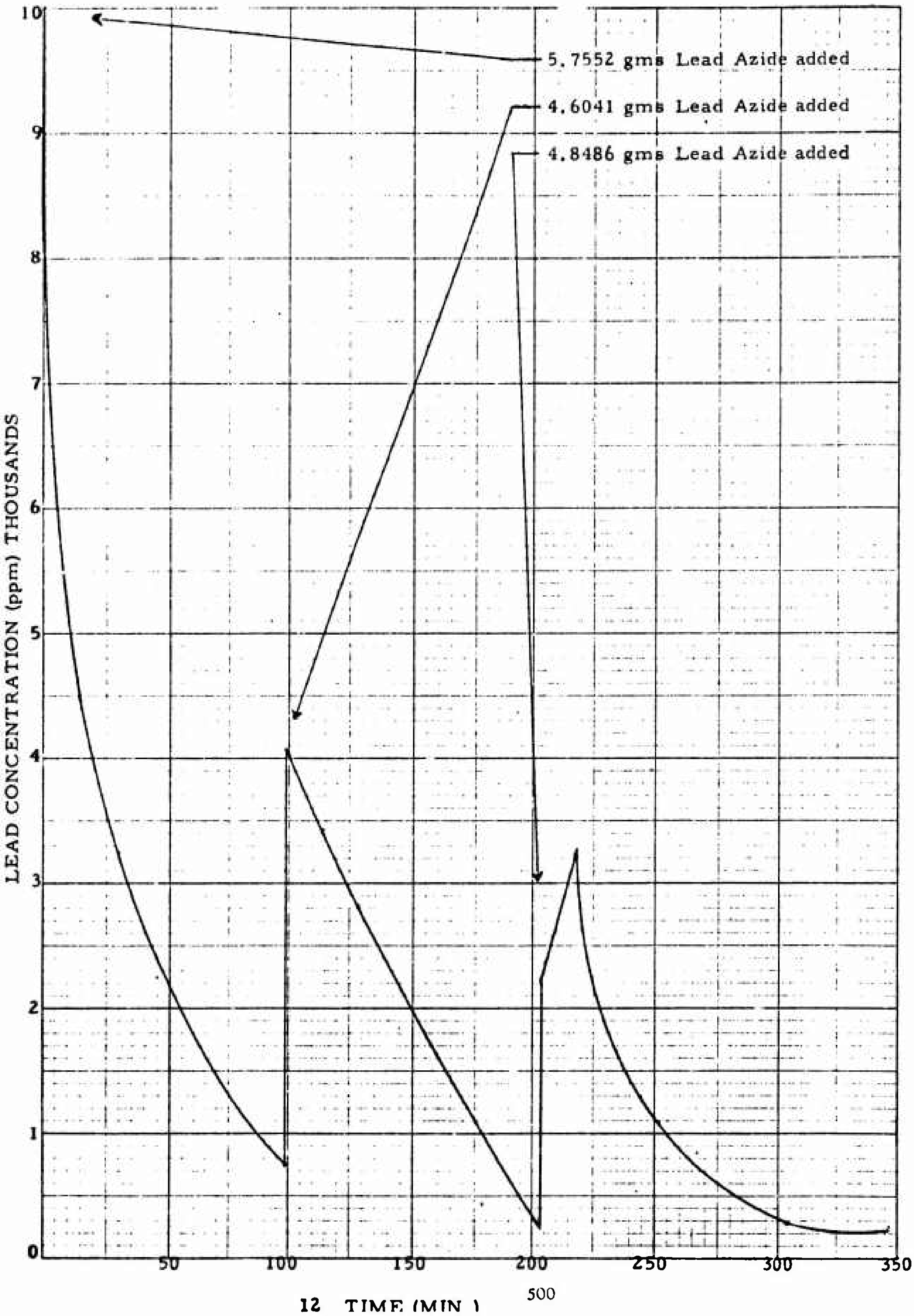
Original weight of lead present in 3.7169 gms
of 98.6 per cent pure lead azide = 2.6072

Per cent of Lead accounted for = 98.17

The above data is from an experiment which parallels the procedures used in the experiment on pages 8, 9 and 10. It is for information purposes only and gives a typical accounting of exact lead recovery.

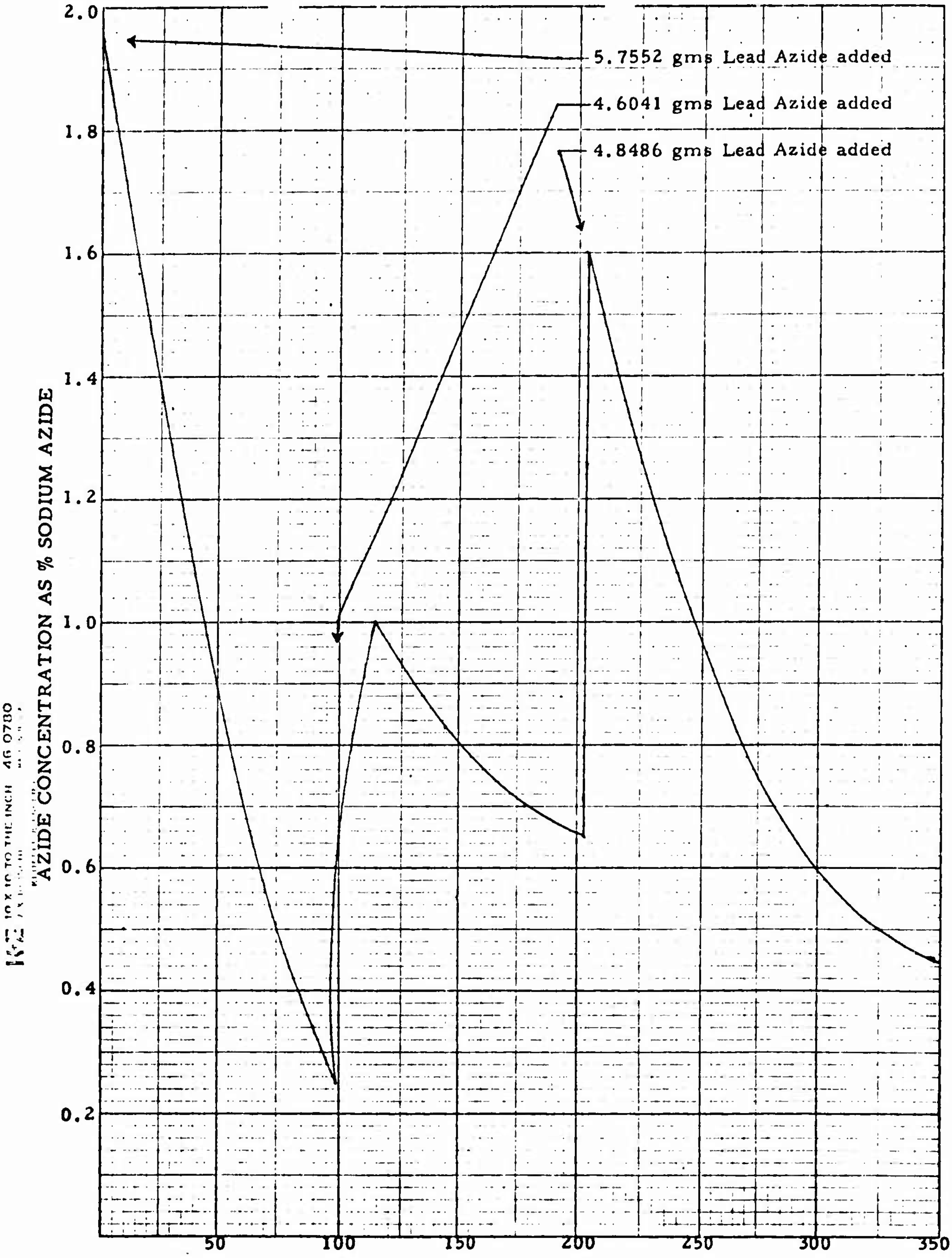
TABLE 5. FINAL DISTRIBUTION OF LEAD IN ELECTROLYSIS AND FLUXING OPERATIONS

FIGURE I. CHANGE IN LEAD CONCENTRATION DURING CYCLING



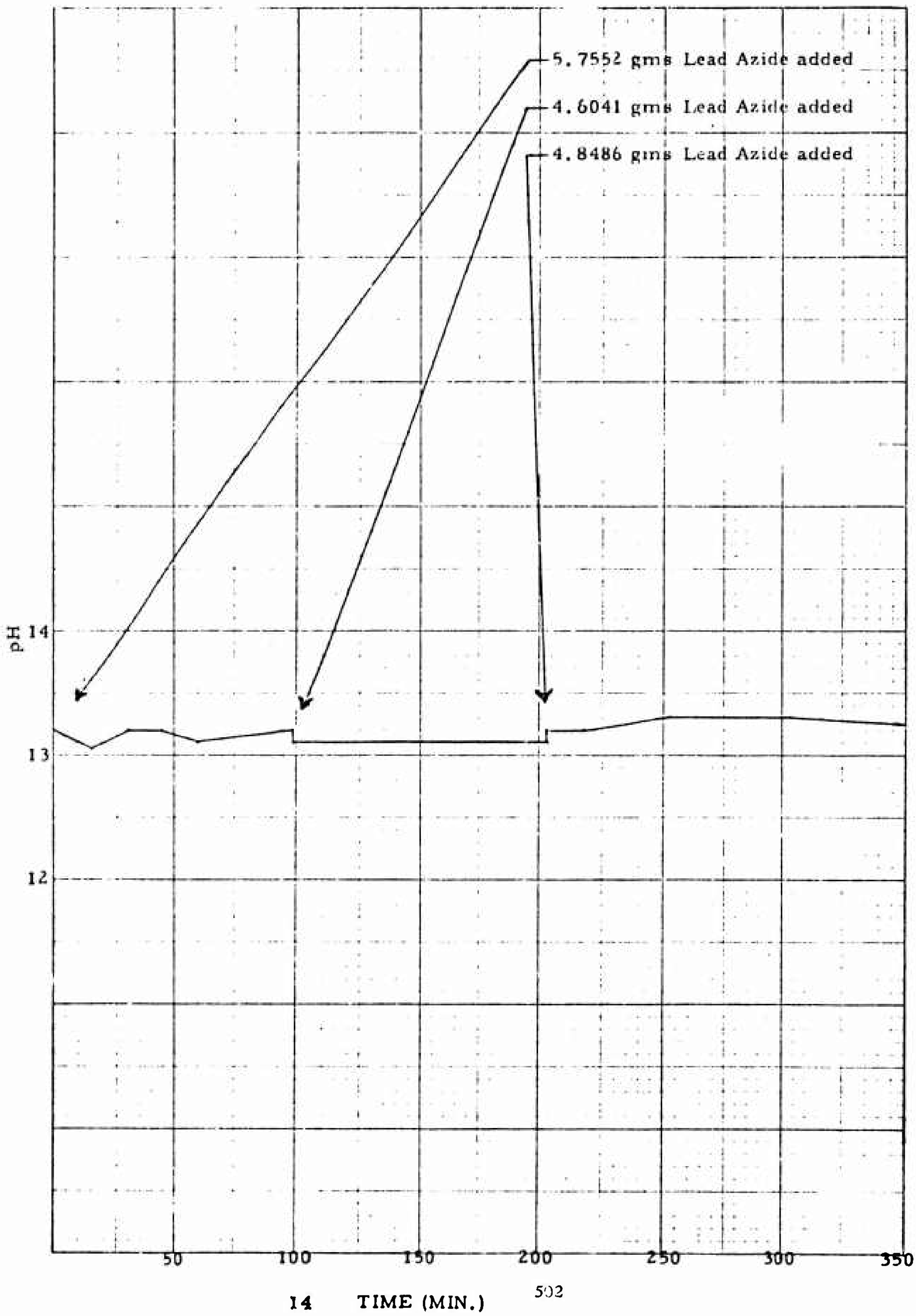
500

FIGURE II. CHANGE IN AZIDE CONCENTRATION DURING CYCLING



501

FIGURE III. CHANGE OF pH DURING CYCLING



GAS EVOLVED

CATHODE		ANODE	
H_2	98.66	N_2	41.98
N_2	1.42	O_2	48.82
O_2	0.30	CO_2	9.20
A	0.02		

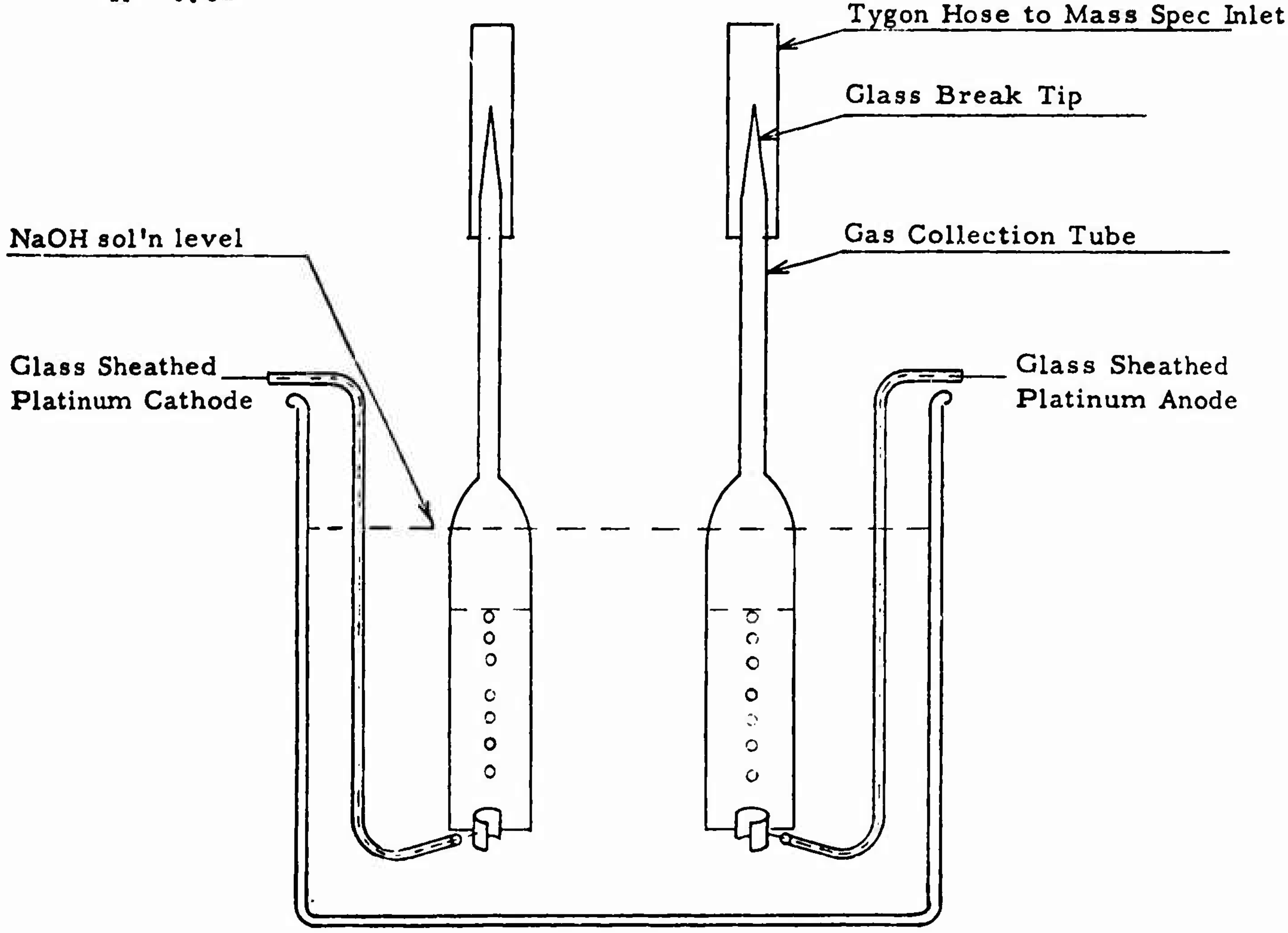


FIGURE IV.

Reactions

No. 1. Dissolving Lead Azide in NaOH Solution

$$Pb(N_3)_2 + 3NaOH + H_2O \rightarrow Pb(OH)_2 + 2NaN_3 + NaOH + H_2O$$

No. 2. Electrolysis (Overall Reaction)

$$Pb^{++} + 2\,N_3^- + 6\,H_2O + 6e^- \rightarrow Pb + 2H_2\uparrow + 3N_2\uparrow + O_2\uparrow + \underbrace{4OH^- + 4H^+}_{4H_2O} + 6e^-$$

Simplified

$$Pb^{++} + 2N_3^- + 2H_2O \rightarrow Pb + \underbrace{2H_2\uparrow}_{\text{(cathode)}} + \underbrace{3\,N_2\uparrow + O_2\uparrow}_{\text{(anode)}}$$

No. 3. Individual Electrolysis Reactions

A. Cathode

$$Pb^{++} + 2e^- \rightarrow Pb$$
$$4\,H_2O + 4e^- \rightarrow 2H_2\uparrow + 4OH^-$$

B. Anode

$$2N_3^- \rightarrow 3N_2 + 2e^-$$
$$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$$

FIGURE 5

A NEW METHOD OF MELTING EXPLOSIVES FOR MELT POUR OPERATIONS

Moderator:

Joe M. Sirls
Harvey Aluminum Sales, Inc.
Milan Army Ammunition Plant
Milan, Tennessee

BLANK PAGE

THE PRIMARY SUBJECT OF THIS SESSION WILL BE THE MELTING OF EXPLOSIVES IN PREPARATION FOR CAST LOADING.

BEFORE I PRESENT TO YOU WHAT WE AT MILAN ARMY AMMUNITION PLANT HAVE DONE IN THIS AREA, DURING THE PAST FEW MONTHS, I WOULD LIKE TO SHOW A FEW SLIDES OF A TYPICAL CONVENTIONAL MELT-POUR OPERATION AND REMIND YOU OF SOME OF THE HIGHLY UNDESIRABLE FEATURES AS WELL AS SOME VERY SERIOUS POTENTIAL SAFETY HAZARDS.

LET'S LOOK FIRST AT THE PHYSICAL LAYOUT AT A TYPICAL LAP LINE.

<u>SLIDE #1</u>

THIS IS A PLOT PLAN OF A MELT LOAD LINE AT MILAN ARMY AMMUNITION PLANT. LOCATED IN THE CENTER OF THE LINE ARE TWO (2) MELT-POUR BUILDINGS. ON EITHER END OF THE LINE IS AN ASSEMBLY BUILDING. ON ONE END OF THE LINE ARE TWO (2) WAREHOUSES. THE SMALL BUILDINGS OUT BACK ARE EXPLOSIVE STORAGE MAGAZINES.

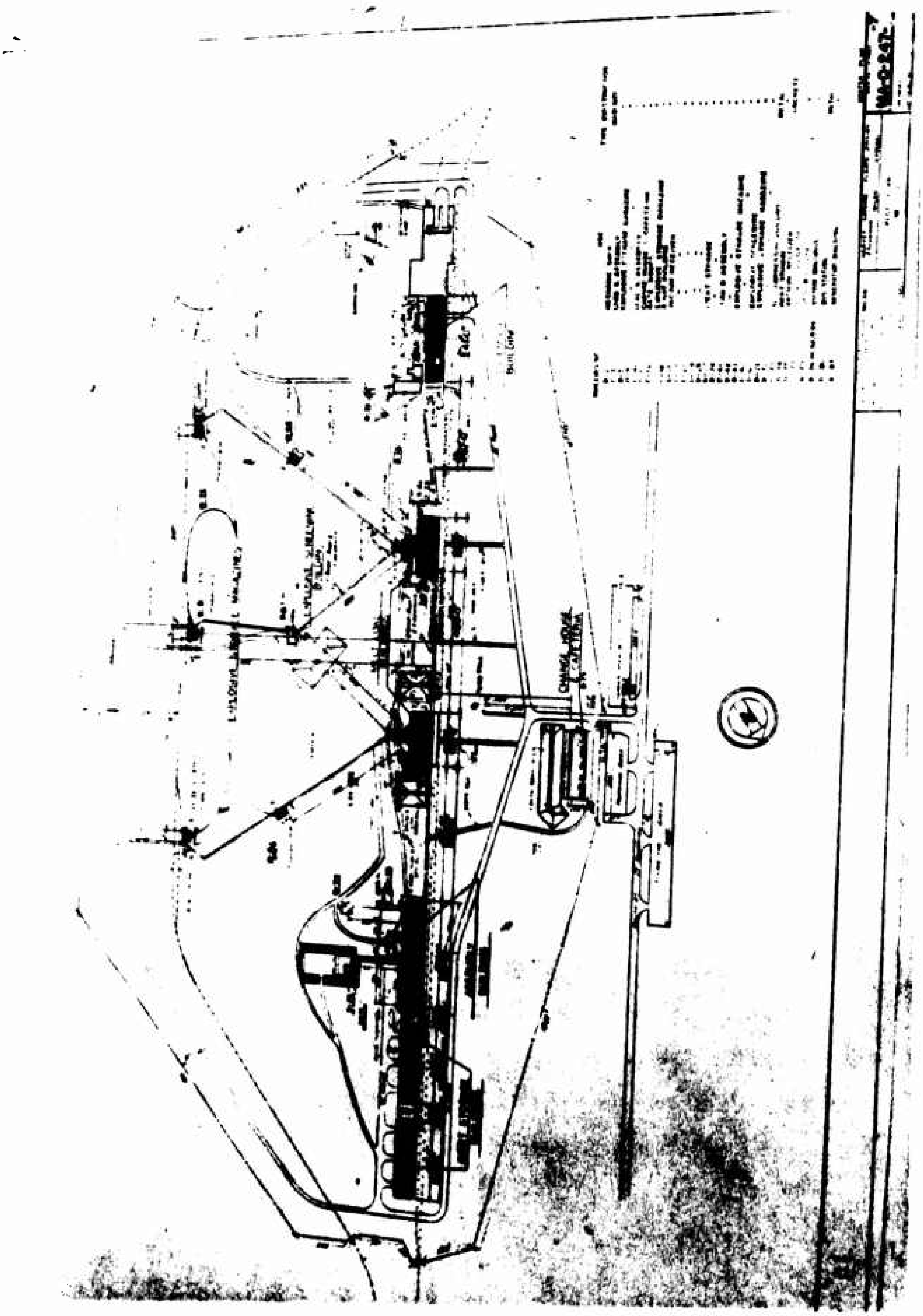
<u>SLIDE #2</u> (PHOTOGRAPHS NOT AVAILABLE)

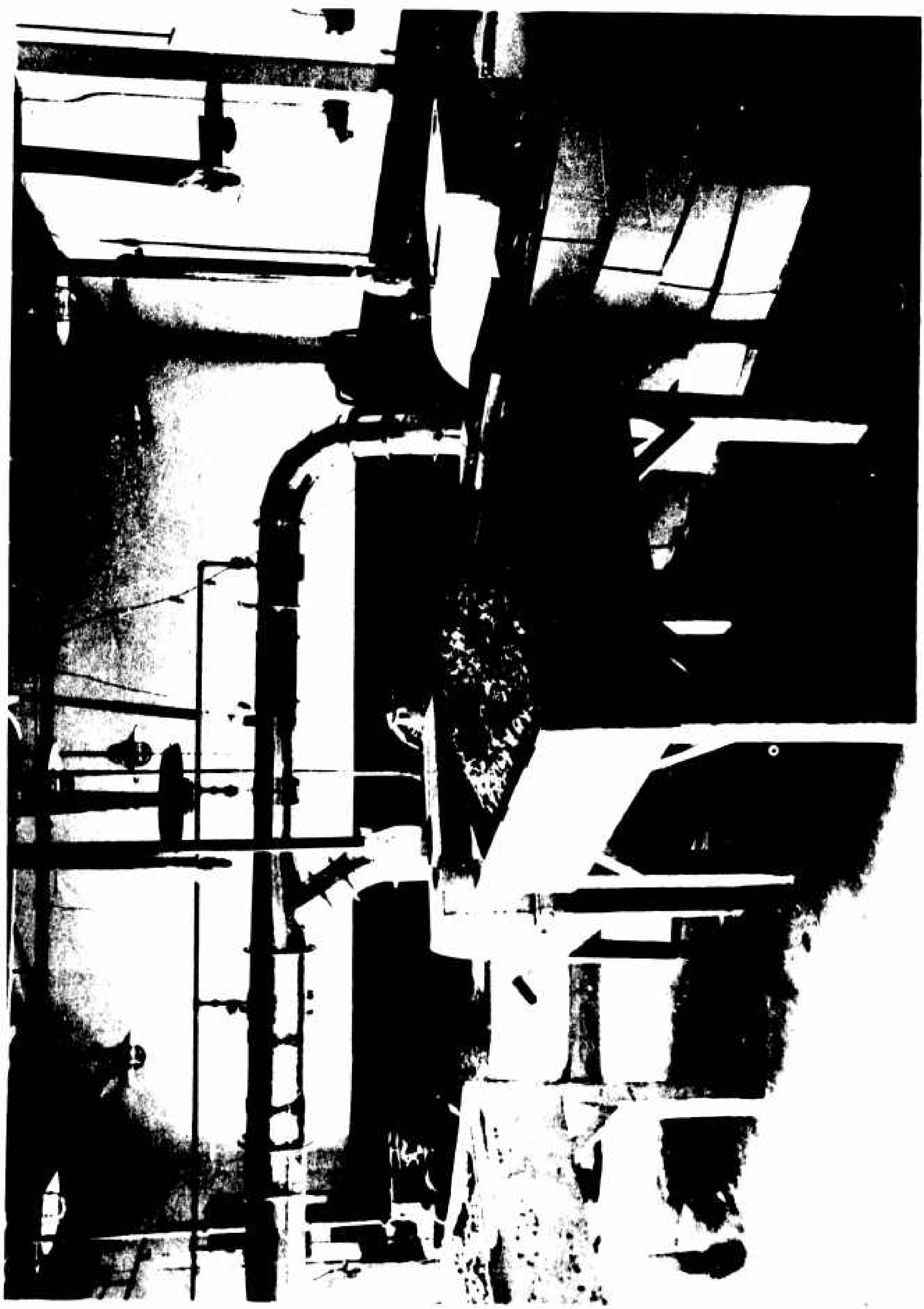
THIS IS A CLOSE-UP VIEW OF ONE OF THE MELT-POUR BUILDINGS. THE BACK PORTION OF THE BUILDING IS THREE (3) STORY. THIS IS WHERE THE EXPLOSIVE IS MELTED AND POURED. THE FRONT PORTION OF THE BUILDING IS FOR COOLING OF THE CAST AND CONSISTS OF SEVEN (7) BAYS 20 FEET WIDE AND 50 FEET LONG WITH 12 INCH REINFORCED CONCRETE DIVIDING WALLS.

NOW LET'S TAKE A LOOK INSIDE THE THREE (3) STORY MELT-POUR SECTION.

<u>SLIDE #3</u>

THIS IS A VIEW OF THE THIRD FLOOR. THE BULK EXPLOSIVE IS BROUGHT IN FROM THE BACK MAGAZINES ON HAND TRUCKS AND UP TO THE THIRD FLOOR BY ELEVATOR. HERE IT IS REMOVED FROM THE CARDBOARD CARTONS AND PASSED OVER A MAGNETIC TABLE INTO THESE HOPPERS. FROM THESE HOPPERS IT FLOWS BY GRAVITY INTO SYNTRON VIBRATORY FEEDERS LOCATED ON THE SECOND FLOOR. NORMAL OPERATING QUANTITY OF EXPLOSIVE ON THIS FLOOR IS APPROXIMATELY 3,000 POUNDS.





SLIDE #4

THIS IS A VIEW OF THE SECOND FLOOR. THIS IS WHERE THE EXPLOSIVE IS MELTED. THE MELTING EQUIPMENT IN THIS PARTICULAR SYSTEM CONSISTS OF TWO (2) 350 GALLON STEAM JACKETED KETTLES AND ONE (1) 150 GALLON KETTLE. NEW FLAKE EXPLOSIVE IS FED INTO THE KETTLES BY SYNTRON VIBRATORY FEEDERS.

RISER SCRAP IS ALSO FED INTO THE KETTLES ON THIS FLOOR. IT IS PASSED OVER A STRONG MAGNETIC TABLE PRIOR TO GOING INTO THE KETTLE.

THE NORMAL OPERATING QUANTITY OF EXPLOSIVE ON THIS FLOOR IS APPROXIMATELY 12,000 POUNDS

SLIDE #5

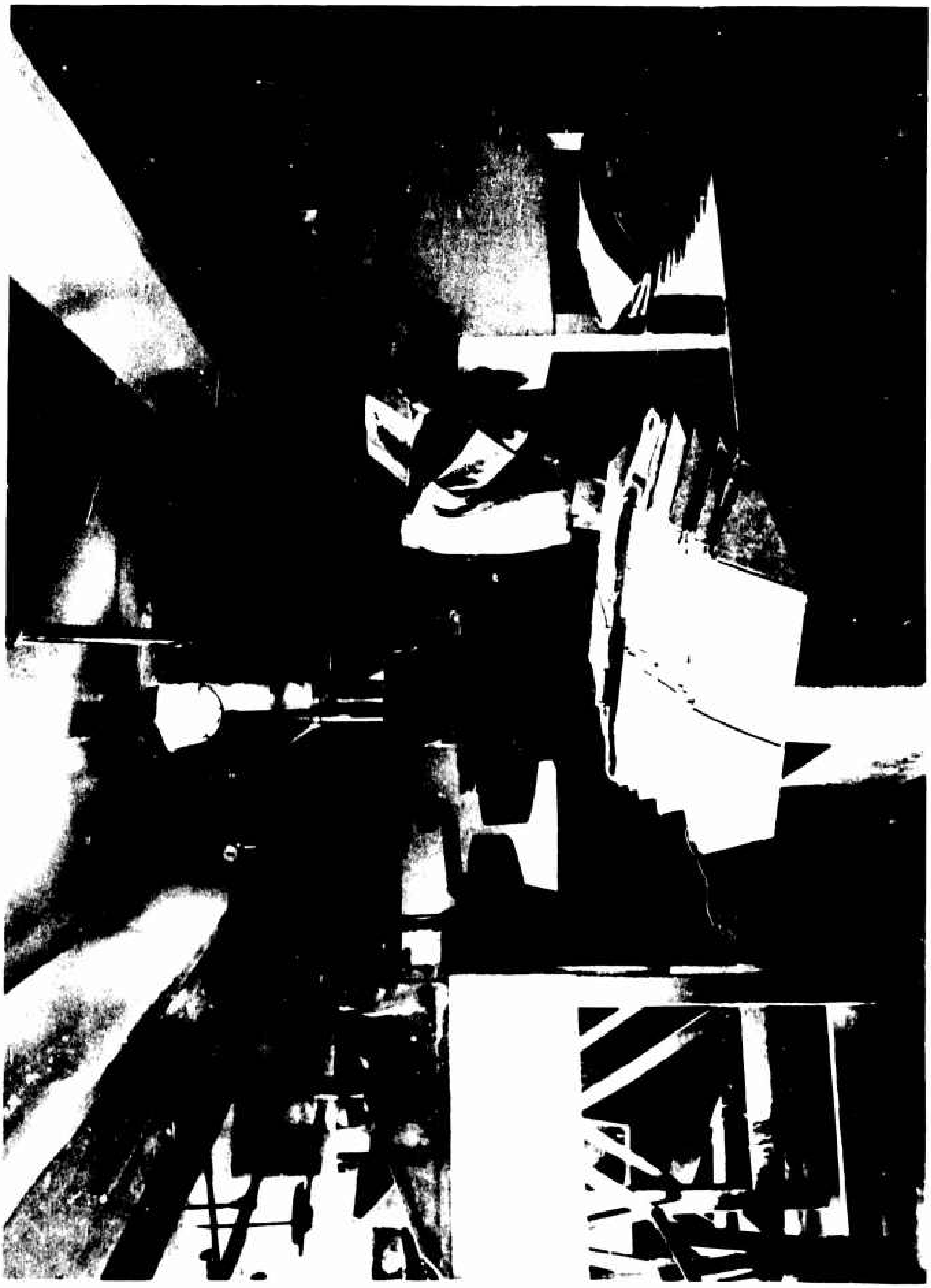
THIS IS A VIEW OF THE POURING OPERATION ON THE FIRST FLOOR. THE METHOD OF POURING EXPLOSIVE VARIES FROM ONE PLANT TO ANOTHER AND EVEN WITHIN A GIVEN PLANT BUT IN MOST ALL POURING OPERATIONS, REGARDLESS OF THE METHOD, THERE IS A CONSIDERABLE AMOUNT OF EXPLOSIVE INVOLVED WHICH IS SUBJECT TO SYMPATHETIC DETONATION, IN THE EVENT OF AN ACCIDENTAL DETONATION AT ANY POINT THROUGHOUT THE MELT-POUR OPERATION. FOR EXAMPLE, IN THIS PARTICULAR MELT-POUR OPERATION THE TOTAL AMOUNT OF EXPLOSIVE INVOLVED, SUBJECT TO SYMPATHETIC DETONATION, WOULD BE APPROXIMATELY 18,000 POUNDS.

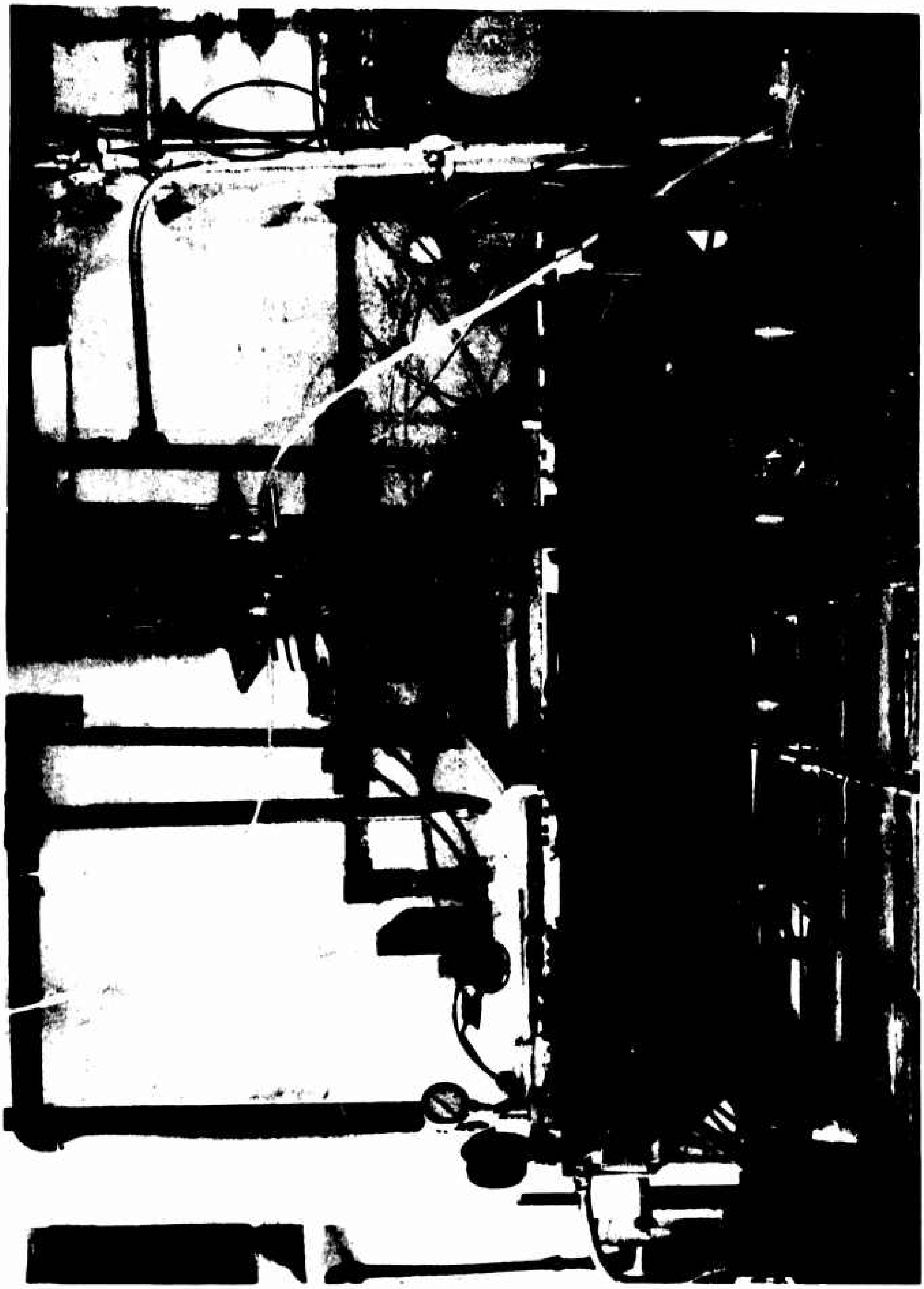
SLIDE #6

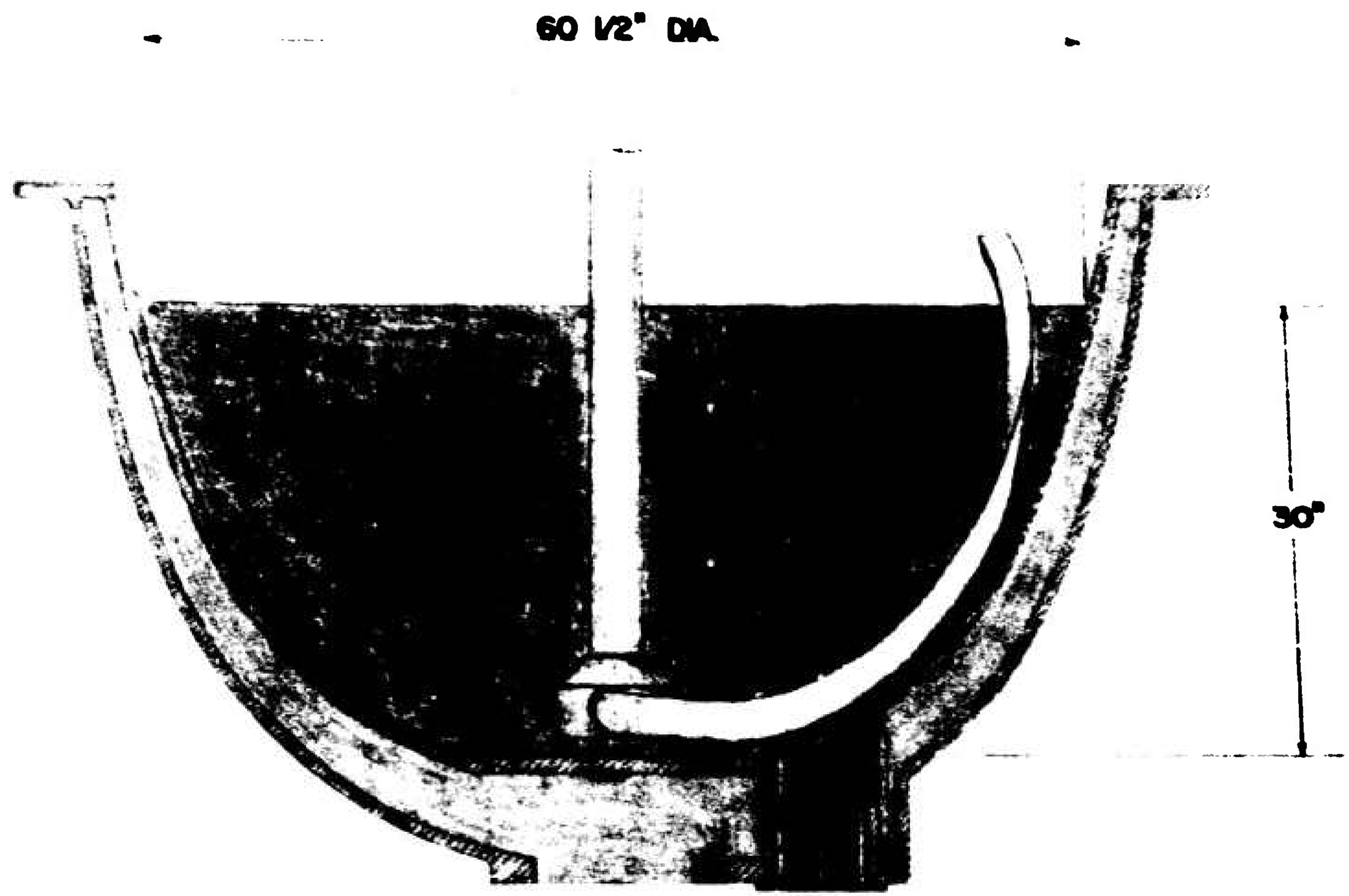
NOW LET'S GO BACK AND TAKE A CLOSER LOOK AT THE MELT KETTLE. THIS DRAWING SHOWS A CROSS SECTION OF A 350 GALLON KETTLE.

THE NORMAL OPERATING QUANTITY OF EXPLOSIVE IS APPROXIMATELY 4,000 POUNDS.

ACTUALLY WITH THIS PRINCIPLE WE ARE MELTING EXPLOSIVE WITH EXPLOSIVE AND DEPENDING MOSTLY ON THE THERMAL CONDUCTIVITY OF THE EXPLOSIVE, WHICH IS VERY POOR, FOR TRANSFER OF HEAT. THIS IS THE REASON FOR THE LARGE VOLUME OF THE KETTLE.







CONVENTIONAL EXPLOSIVE MELTING KETTLE

THE RAMS-HORN TYPE AGITATOR LEAVES A LOT TO BE DESIRED FROM THE SAFETY STANDPOINT

THE AGITATOR BLADE CLEARS THE BOTTOM OF THE KETTLE APPROXIMATELY 3/4 OF AN INCH. THIS CREATES A POSSIBLE PINCH POINT ESPECIALLY WHERE THE BLADES PASS OVER THE PERFORATED STRAINER COVER PLATE.

THE NEXT SLIDE SHOWS WHAT CAN HAPPEN WHEN EXTRANEOUS MATERIAL GETS INTO THE MELT KETTLE.

SLIDE #7

THIS IS A 40MM, M406 BALL AND SKIRT ASSEMBLY.

THIS IS THE WAY IT APPEARED AFTER HAVING SPENT SOME TIME IN A CONVENTIONAL MELT KETTLE

NOW I WOULD LIKE TO SHOW YOU WHAT CAN HAPPEN AS A RESULT OF AN ACCIDENTAL DETONATION IN A CONVENTIONAL MELT-POUR BUILDING.

THE ONLY COMMENT I WILL MAKE IS THAT IT IS MY UNDERSTANDING THAT THERE WAS AN ESTIMATED 13,000 POUNDS OF EXPLOSIVES INVOLVED IN THE INITIAL EXPLOSION, IN THE MELT BUILDING.

SLIDES #8 THRU #18 (PHOTOGRAPHS NOT AVAILABLE FOR THIS PAPER)

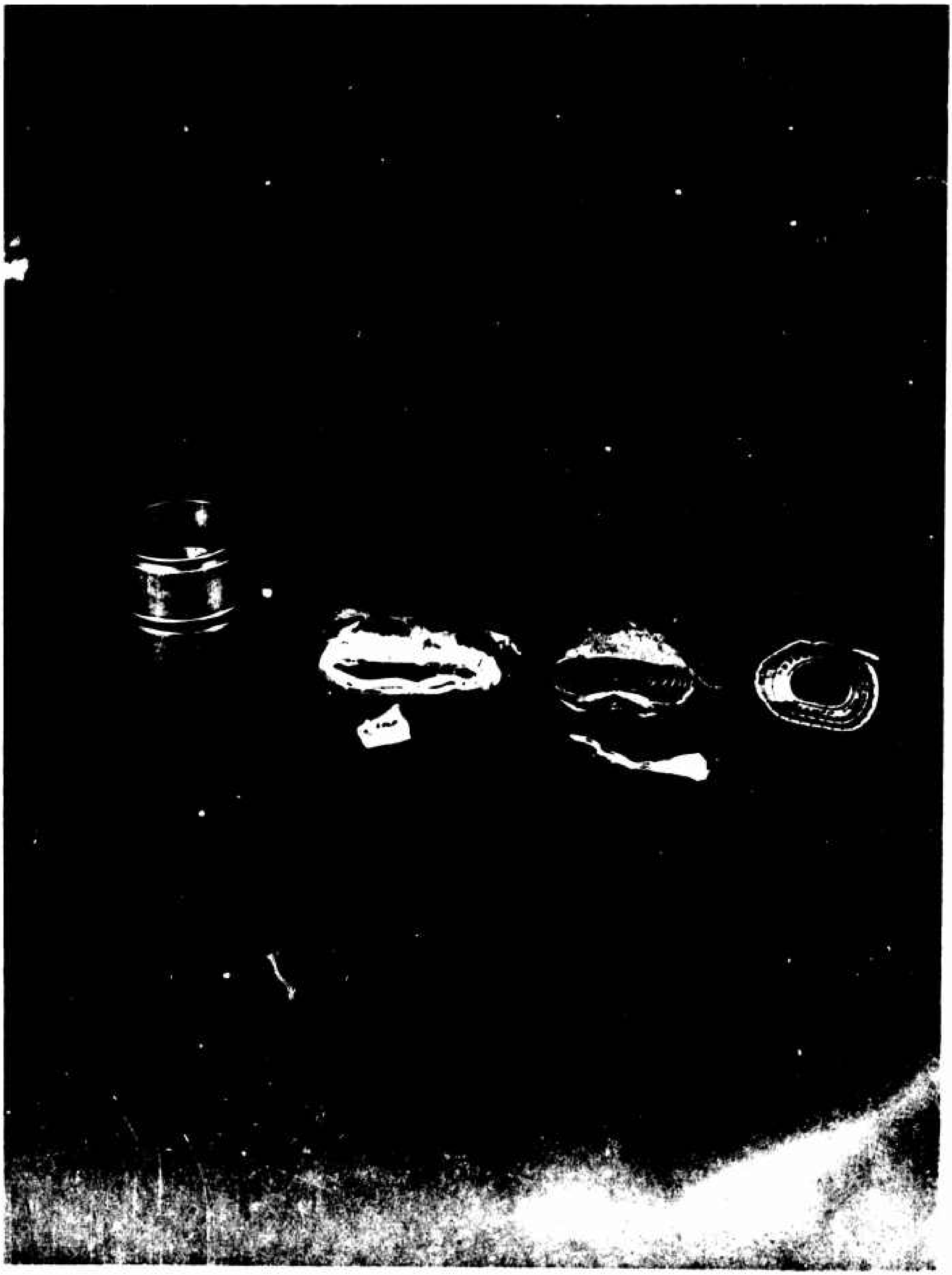
GENTLEMEN, IN MY OPINION, ANY NEW METHOD OF MELTING AND CAST LOADING HIGH EXPLOSIVE THAT DOESN'T ELIMINATE THE POSSIBILITY OF THIS TYPE OF AN INCIDENT IS NOT WORTHY OF CONSIDERATION.

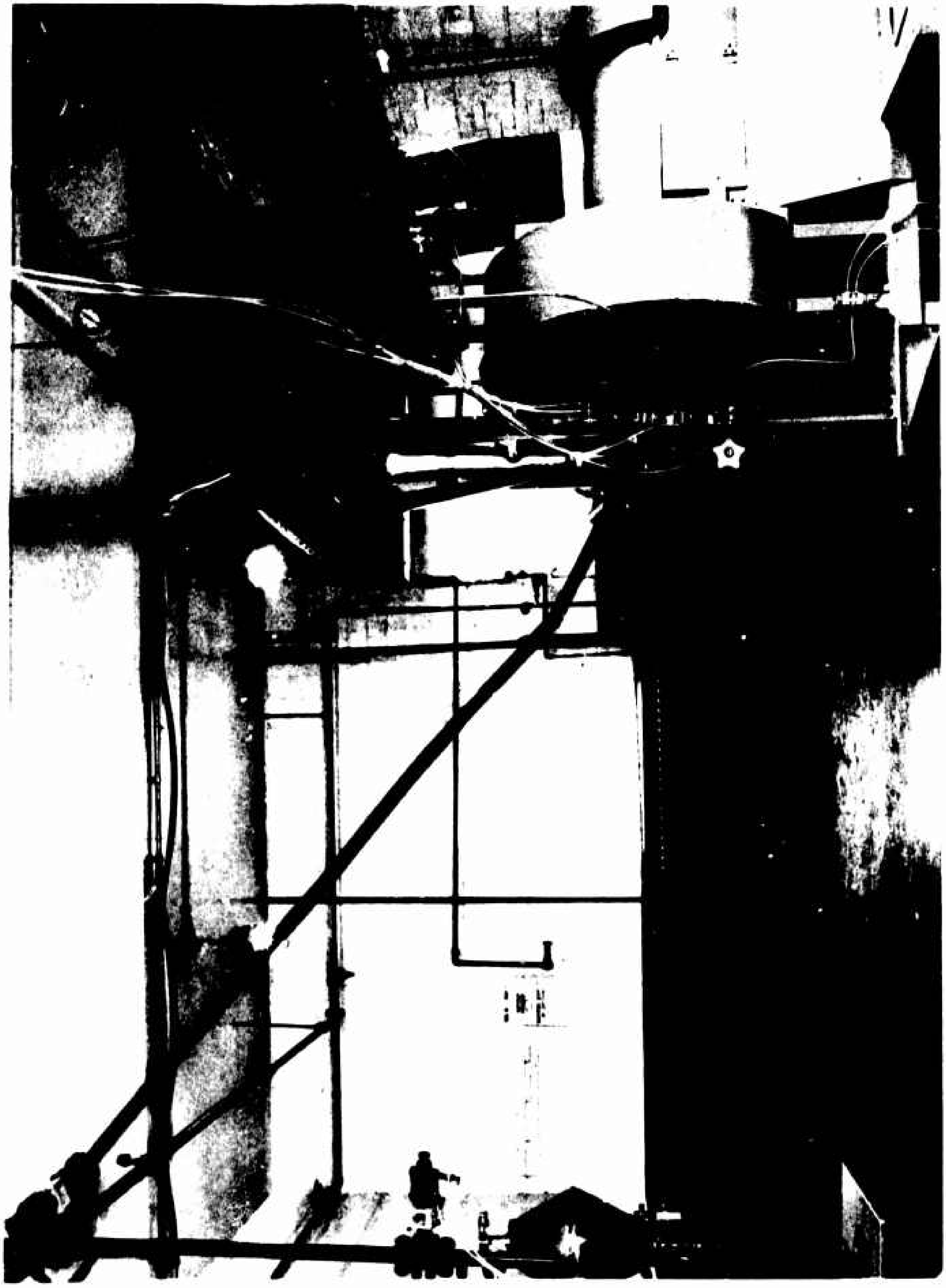
NOW LET'S TAKE A LOOK AT AN ENTIRELY NEW APPROACH TO MELTING EXPLOSIVES.

SLIDE #19

THIS IS AN OVERALL VIEW OF THE SYSTEM IN ITS CURRENT STATE OF DEVELOPMENT.

THE BASIC PRINCIPLE INVOLVED IS THE USE OF 15 POUNDS LIVE STEAM IN DIRECT CONTACT WITH THE EXPLOSIVE. THIS MAKES POSSIBLE A HIGH CAPACITY, LOW VOLUME MELTING UNIT.





THIS IS THE MELTING UNIT. THIS IS A 60 POUND CAPACITY UNIT. THE ACTUAL MELTING TIME FOR A 60 POUND BATCH OF FLAKE EXPLOSIVE IS APPROXIMATELY 30 SECONDS. ALLOWING 30 SECONDS TO CHARGE AND EMPTY A 60 POUND BATCH GIVES AN OVERALL CYCLE TIME OF 60 SECONDS. FULLY AUTOMATED, 60 POUNDS EVERY 60 SECONDS WOULD RESULT IN A MELTING RATE OF 3600 POUNDS/HOUR.

DURING CERTAIN PHASES OF THE OVERALL CYCLE, THIS INTERLOCK HOPPER CONTAINS 60 POUNDS OF FLAKE EXPLOSIVE, WHICH MEANS THAT THE TOTAL QUANTITY OF EXPLOSIVE INVOLVED IN THE OPERATION OF THIS UNIT IS 120 POUNDS.

NOW LET'S START AT THE BEGINNING OF THE CYCLE AND IDENTIFY EACH COMPONENT PART OF THE SYSTEM AND ITS FUNCTION.

SLIDE #20

THIS IS A 60 POUND CAPACITY HOPPER LOCATED ON THE SECOND FLOOR ABOVE THE MELTING UNIT. IN AN ACTUAL PRODUCTION SYSTEM THIS HOPPER WOULD BE LOCATED IMMEDIATELY ABOVE THE INTERLOCK HOPPER ON THE MELTING UNIT. IN A HIGHLY AUTOMATED SYSTEM, IT WOULD BE CHARGED AT THE APPROPRIATE TIME OF THE CYCLE SO AS TO HAVE 60 POUNDS OF EXPLOSIVE AVAILABLE TO BE DROPPED INTO THE INTERLOCK HOPPER WITHOUT DELAY IN THE CYCLE

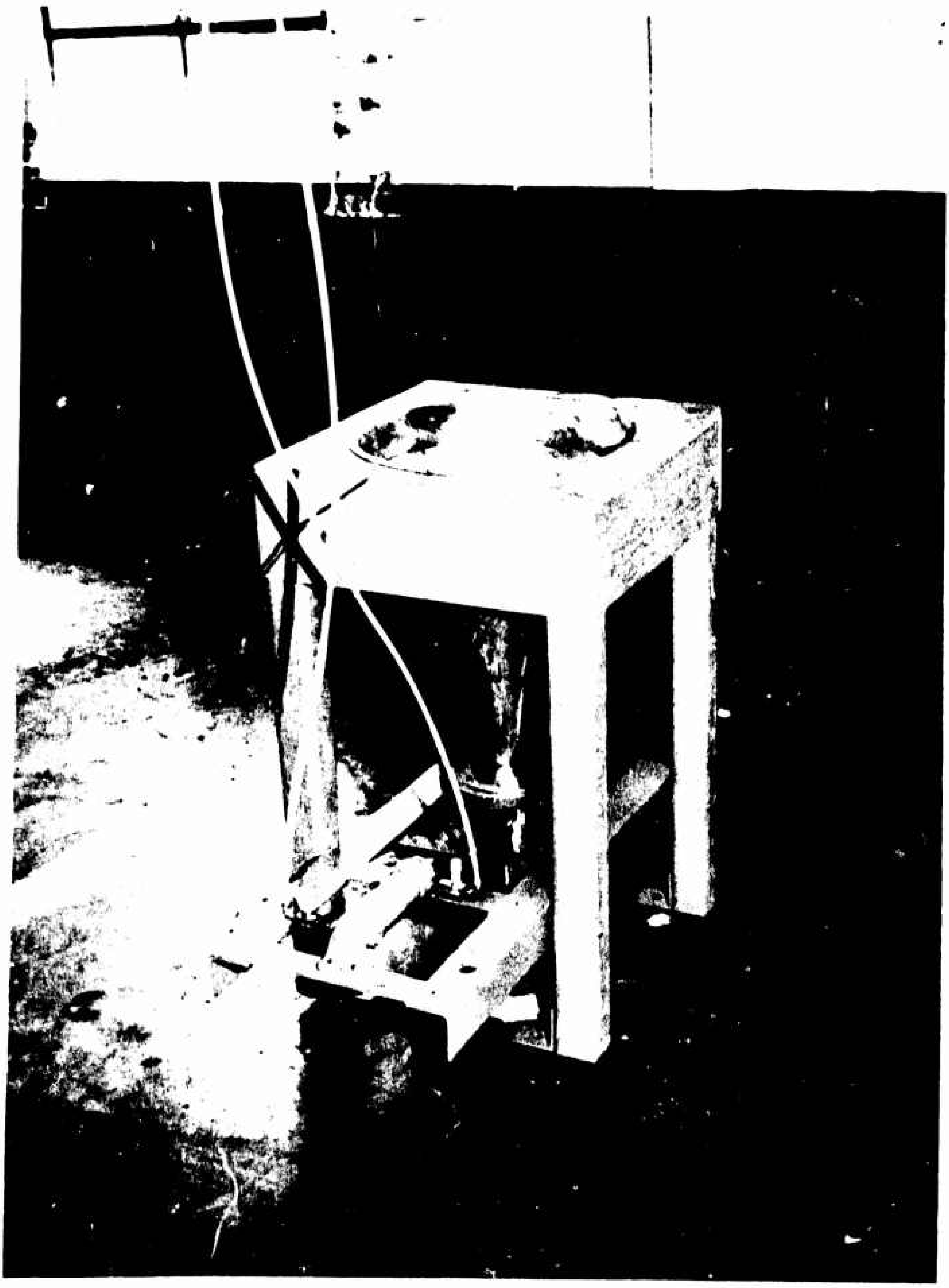
SLIDE #21

THIS IS THE INTERLOCK HOPPER, CONNECTED TO THE HOPPER ABOVE BY THIS TUBE.

THIS IS A SPECIAL FLAPPER VALVE THAT PERMITS THE FLAKE EXPLOSIVE TO FLOW FREELY FROM THE HOPPER ABOVE INTO THE INTERLOCK HOPPER.

SLIDE #22 (PHOTOGRAPHS NOT AVAILABLE FOR THIS PAPER)

THIS IS A CLOSE-UP VIEW OF THE VALVE WITH THE COVER PLATE REMOVED. THIS TUBE IS ON A 45 DEGREE ANGLE AND CUT SQUARE ON THE END. THE FLAPPER IS A FLAT ALUMINUM DISC 1/8 INCH THICK ATTACHED TO A TEFLON HINGE AT THE TOP. AN "O" RING IN THE FACE OF THE FLANGE ON THE END OF THE TUBE EFFECTS THE SEAL.



IN THE OPEN POSITION, AS SHOWN HERE THE FLAPPER HANGS STRAIGHT DOWN. IT IS CLOSED BY AN AIR JET DIRECTED ON THIS SIDE OF THE FLAPPER AND IS HELD CLOSED BY BACK PRESSURE.

THE FLAPPER DROPS OPEN WHEN THE PRESSURE IN THE INTERLOCK HOPPER APPROACHES ATMOSPHERIC PRESSURE.

SLIDE #23

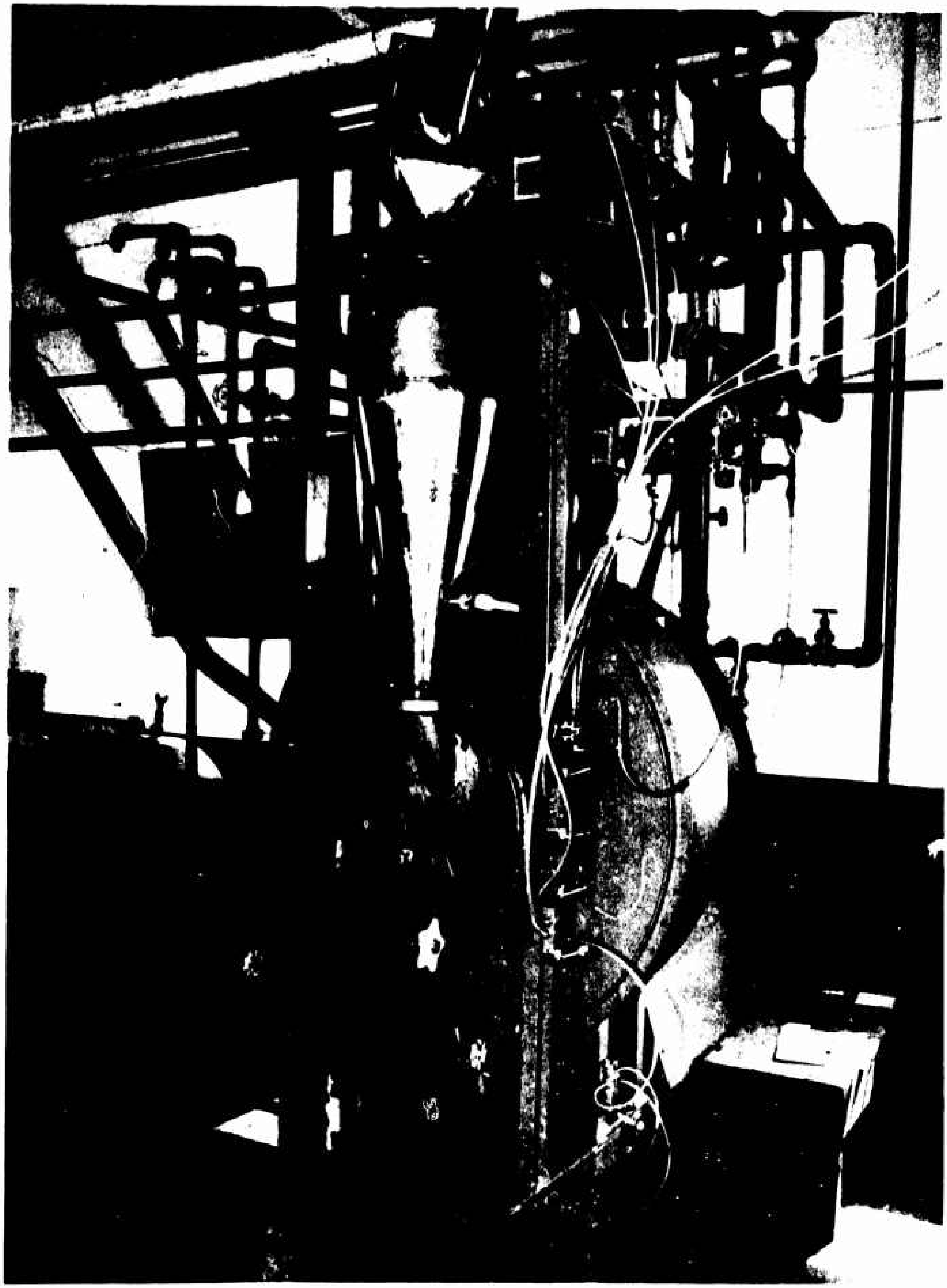
THE PURPOSE OF THE INTERLOCK HOPPER IS TO MAKE IT POSSIBLE TO CHARGE THE MELTING UNIT WITH 60 POUNDS OF FLAKE EXPLOSIVE WHILE UNDER 15 POUNDS STEAM PRESSURE. THIS IS ACCOMPLISHED BY PRESSURIZING THE INTERLOCK HOPPER WITH AIR TO APPROXIMATELY 14.5 P.S.I.

ON THE END OF THIS FILL TUBE, INSIDE THE MELTING UNIT IS THE SAME TYPE FLAPPER VALVE AS THE ONE ON TOP OF THE INTERLOCK HOPPER AND IS HELD CLOSED BY STEAM PRESSURE.

THE FLAKE EXPLOSIVE IS HELD IN THE UPPER PART OF THE INTERLOCK HOPPER BY A FLAT HALF-CIRCLE VALVE UNTIL THE INTERLOCK HOPPER IS PRESSURIZED AND THE FLAPPER VALVE ON THE END OF THE FILL TUBE OPENS. AT THAT TIME THIS VALVE IS OPENED WHICH ALLOWS THE FLAKE EXPLOSIVE TO FLOW BY GRAVITY DIRECTLY INTO THE MELTING UNIT.

WHEN ALL THE EXPLOSIVE HAS FLOWED FROM THE INTERLOCK HOPPER INTO THE MELTING UNIT, THE INTERLOCK HOPPER IS VENTED THROUGH A 1-1/2 INCH AIR LINE.

THE SUDDEN MOVEMENT OF STEAM, CAUSED BY THE VENTING OF THE INTERLOCK HOPPER, IMMEDIATELY CLOSES THE FLAPPER VALVE ON THE END OF THE FILL TUBE. WHEN THE PRESSURE IN THE INTERLOCK HOPPER DROPS TO NEAR ATMOSPHERIC PRESSURE, THE FLAPPER VALVE ON TOP OF THE INTERLOCK HOPPER, WHICH HAS BEEN HELD CLOSED BY BACK PRESSURE, DROPS OPEN AND THE INTERLOCK HOPPER IS NOW READY TO RECEIVE ANOTHER 60 POUND BATCH FROM THE HOPPER ABOVE



NOW LET'S TAKE A LOOK INSIDE THE MELTING UNIT AND SEE HOW IT IS CONSTRUCTED AND ALSO WHAT TAKES PLACE DURING THE CHARGING, MELTING AND EMPTYING CYCLE.

TO DO THIS WE WILL HAVE TO CHANGE NOW TO VIEWGRAPHS (PHOTOGRAPHS NOT AVAILABLE FOR THIS PAPER)

VIEWGRAPH #1 - MELTING UNIT WITH FRONT COVER PLATE REMOVED SHOWING INNER STAINLESS STEEL REVOLVING DRUM INSIDE THE STEAM JACKETED DRUM.

VIEWGRAPH #2 - STAINLESS STEEL DRUM CONSTRUCTION AND SUPPORTING MECHANISM.

VIEWGRAPH #3 - CONSTRUCTION FEATURES OF FRONT OF STAINLESS STEEL DRUM.

VIEWGRAPH #4 - SIDE VIEW OF STAINLESS STEEL DRUM.

VIEWGRAPH #5 - BAFFLE ARRANGEMENT IN STAINLESS DRUM.

VIEWGRAPH #6 - FIXED INNER HOPPER, FILL TUBE AND VENT ASSEMBLY.

VIEWGRAPH #6A - RIGHT HAND VIEW OF SAME.

VIEWGRAPH #7 - EXPLODED VIEW OF MELTING UNIT. (VIEWED FROM LEFT SIDE)

VIEWGRAPH #7A - EXPLODED VIEW OF MELTING UNIT. (VIEWED FROM RIGHT SIDE)

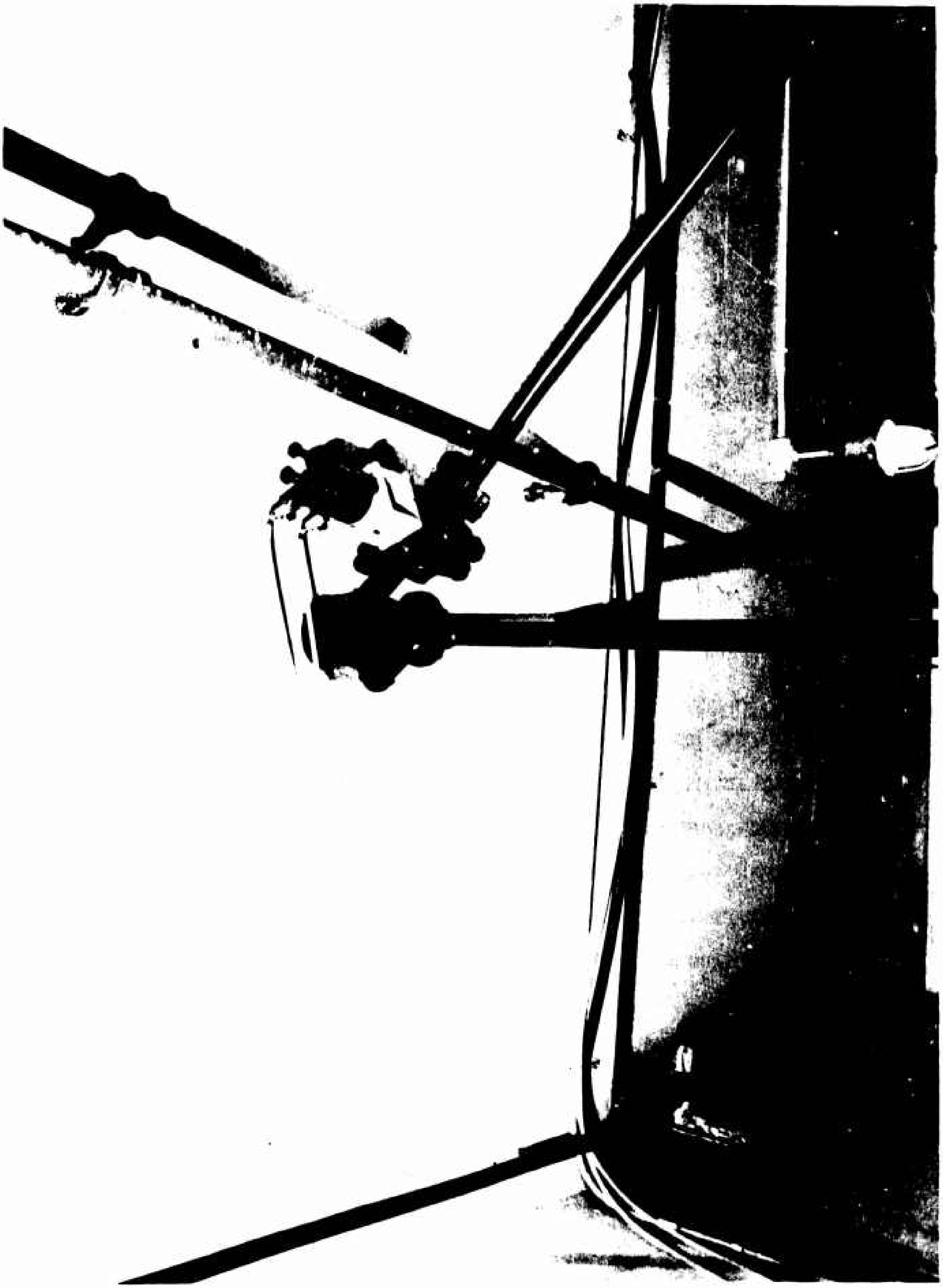
NOW LET'S GO BACK AND CONTINUE THROUGH THE DRAW-OFF PORTION OF THE CYCLE.

SLIDE #24

THIS IS THE DRAW-OFF LINE WHICH IS ATTACHED TO THE 3/4 INCH LINE IN THE FIXED HOPPER INSIDE THE MELTING UNIT. THE FIXED HOPPER INSIDE IS FULL OF MOLTEN EXPLOSIVE AND IS UNDER 15 POUNDS STEAM PRESSURE. WHEN THE DIAPHRAGM VALVE IN THE DRAW-OFF LINE IS OPENED STEAM PRESSURE ON THE SURFACE OF THE MOLTEN EXPLOSIVE IN THE FIXED HOPPER FORCES THE EXPLOSIVE UP THIS LINE AND INTO A BLOW-DOWN STACK THIS DRAW-OFF LINE WOULD PASS THROUGH A LACED CONCRETE CUBICLE WALL AT ABOUT THIS POINT.

SLIDE #25

THE BLOW-DOWN STACK IS A 4 INCH STEAM JACKETED PIPE APPROXIMATELY EIGHT (8) FEET HIGH



THE 3/4 INCH LINE GOES INTO THE BLOW-DOWN STACK NEAR THE BOTTOM AND ELLS UP.

THE EXPLOSIVE, COMING OUT OF THIS ORIFICE, UNDER PRESSURE, IS FORCED STRAIGHT UP INTO THE BLOW-DOWN STACK AND THEN FALLS BACK BY GRAVITY AND FLOWS DOWN THIS LINE INTO A DECANTER.

AT THE END OF THE EMPTYING CYCLE, STEAM FOLLOWS THE EXPLOSIVE UP THIS LINE, PURGING THE LINE OF EXPLOSIVE, EXCEPT WHAT ADHERES TO THE SIDE WALLS OF THE PIPE. WHEN ALL THE EXPLOSIVE IS FORCED OUT OF THIS LINE, THE INCREASED VELOCITY OF THE STEAM TENDS TO FURTHER CLEAN THIS LINE

SLIDE #26

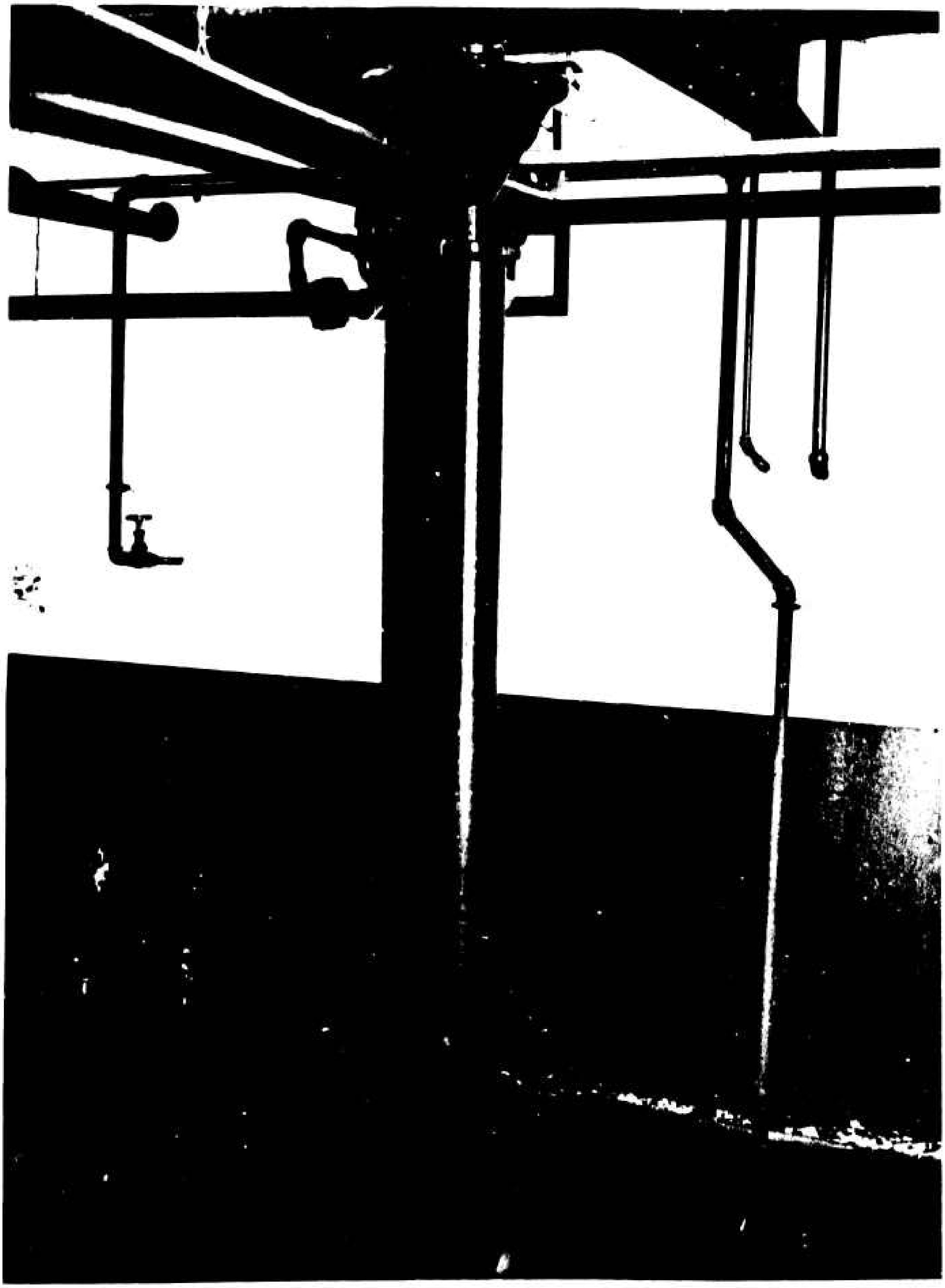
THIS IS THE TOP PART OF THE BLOW-DOWN STACK. IT IS VENTED ON TOP AND THE VOLUME OF THE STACK IS SUCH THAT THE STEAM CAN FLOW FOR A SHORT PERIOD OF TIME BEFORE ANY PRESSURE BUILD-UP OCCURS. WHEN THE STEAM DOES BEGIN TO ESCAPE THROUGH THE VENT ON TOP OF THE STACK, A VALVE IS ACTUATED WHICH IN TURN CLOSES THE DIAPHRAGM VALVE IN THE DRAW-OFF LINE.

WITH THIS PRINCIPLE, IT IS CONCEIVABLE THAT A MODULAR MELT-POUR SYSTEM, CONSISTING OF MULTIPLE MELTING AND EXPLOSIVE CONDITIONING UNITS, COULD BE DESIGNED SO THAT THE QUANTITY OF EXPLOSIVE, SUBJECT TO ACCIDENTAL OR SYMPATHETIC DETONATION, COULD BE HELD TO THE VERY MINIMUM, POSSIBLY 120 POUNDS.

SLIDES #27 & 28

I AM SURE YOU HAVE BEEN WONDERING WHAT HAPPENS TO THE WATER OR CONDENSATE THAT DEVELOPS FROM MELTING A 60 POUND BATCH OF EXPLOSIVE. WELL MOST OF IT IS DECANTED BY THIS UNIT.

HERE IS HOW IT WORKS.



LET'S GO BACK TO THE FIXED HOPPER INSIDE THE MELTING UNIT. AS THIS HOPPER IS BEING FILLED AND DURING THE EMPTYING CYCLE, THE WATER BEING MUCH LIGHTER THAN THE EXPLOSIVE TENDS TO ACCUMULATE ON TOP OF THE EXPLOSIVE, CONSEQUENTLY MOST OF IT COMES OUT AS A MASS AT THE VERY END OF THE EMPTYING CYCLE RATHER THAN BEING UNIFORMLY MIXED THROUGHOUT THE EXPLOSIVE.

SINCE IT DOES COME OUT THE EMPTYING LINE LAST IT REMAINS ON TOP OF THE EXPLOSIVE UNTIL IT IS DECANTED.

SLIDE #29 (PHOTOGRAPHS NOT AVAILABLE FOR THIS PAPER)

NOW LET'S TAKE A LOOK INSIDE THE DECANTER.

THE VOLUME OF THE DECANTER IS A LITTLE LESS THAN THE VOLUME OF 60 POUNDS OF MOLTEN EXPLOSIVE.

IN THE BOTTOM OF THE DECANTER IS A WEIGHTED FLOAT ATTACHED TO THIS 1/4 INCH ROD WHICH EXTENDS THROUGH THE TOP OF THE UNIT THAT WILL FLOAT IN EXPLOSIVE BUT WILL NOT FLOAT IN WATER.

IN THE TOP OF THE UNIT IS ANOTHER FLOAT THAT WILL FLOAT IN EXPLOSIVE BUT WILL NOT FLOAT IN WATER. THIS FLOAT IS FREE TO MOVE UP AND DOWN ON THIS SMALL ROD.

THE TWO (2) FLOATS IN CONJUNCTION WITH THESE PROXIMITY SENSOR HEADS CONTROL THE OPENING AND CLOSING OF THIS AIR OPERATED DIAPHRAGM DRAW-OFF VALVE.

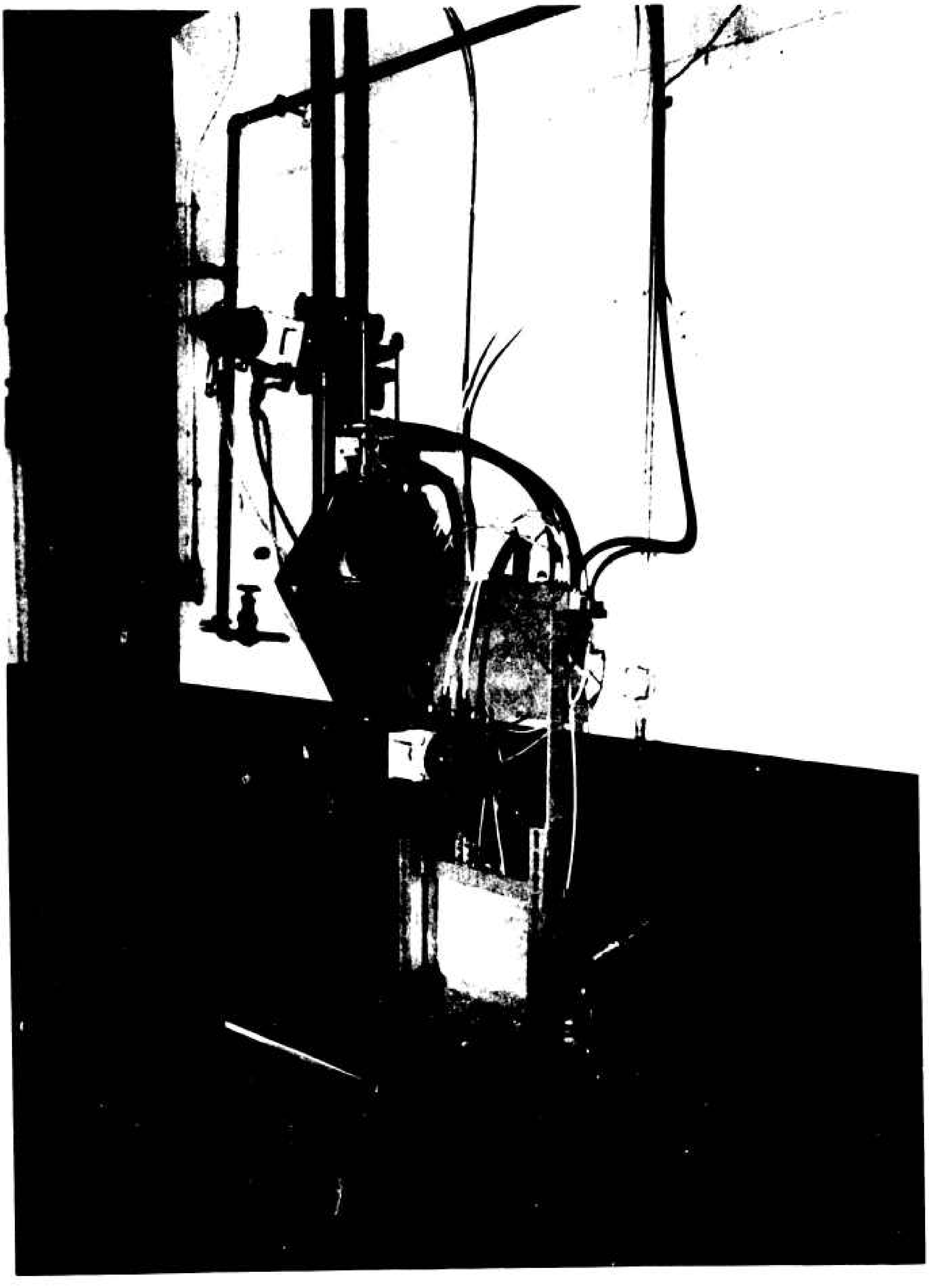
THIS IS THE FILL PIPE COMING FROM THE BLOW-DOWN STACK.

THIS IS AN OVERFLOW PIPE THROUGH WHICH THE WATER IS DECANTED.

THE YELLOW REPRESENTS EXPLOSIVE AND THE BLUE, WATER OR CONDENSATE.

AS SHOWN HERE, THIS WOULD BE THE CONDENSATE FROM THE PREVIOUS 60 POUND BATCH, WHICH IS APPROXIMATELY 6 - 7 OUNCES.

AT THE BEGINNING OF THE NEXT CYCLE, AS THE EXPLOSIVE LEVEL BEGINS TO RISE THE BOTTOM FLOAT RISES APPROXIMATELY 1/2 INCH.



SLIDE #30 (PHOTOGRAPHS NOT AVAILABLE FOR THIS PAPER)

THE EXPLOSIVE LEVEL CONTINUES TO RISE UNTIL IT REACHES A POINT JUST BELOW THE OVERFLOW PIPE. AT THIS POINT ALL BUT A SMALL AMOUNT OF THE WATER HAS BEEN DECANTED.

AT THIS LEVEL THE UPPER FLOAT IS FLOATING IN THE EXPLOSIVE AND HAS MOVED UP TO A POINT WHERE THIS MASS OF METAL ACTUATES THIS PROXIMITY SENSOR HEAD, WHICH IN TURN OPENS THE BOTTOM DRAW-OFF VALVE.

WHEN THE DRAW-OFF VALVE OPENS, THE EXPLOSIVE LEVEL BEGINS TO DROP.

AT THIS TIME THERE IS STILL SOME EXPLOSIVE IN THE FILL PIPE WITH THE CONDENSATE FROM THIS BATCH ON TOP.

SLIDE #31 (PHOTOGRAPHS NOT AVAILABLE FOR THIS PAPER)

AS THE LEVEL CONTINUES TO DROP, THE CONDENSATE IN THE FILL PIPE EVENTUALLY FLOWS OUT OF THE FILL PIPE ON TOP OF THE EXPLOSIVE AND WILL BE DECANTED IN THE NEXT CYCLE.

SLIDE #32 (PHOTOGRAPHS NOT AVAILABLE FOR THIS PAPER)

WHEN THE BOTTOM FLOAT IS NO LONGER SUBMERGED IN EXPLOSIVE AND BEGINS TO MOVE DOWN THE UPPER SENSOR HEAD IS ENERGIZED WHICH CLOSES THE DRAW-OFF VALVE.

MOISTURE CONTENT OF THE EXPLOSIVE COMING FROM THE DECANTER IS APPROXIMATELY .6%.

THE NEXT AND FINAL PHASE OF THE MELTING PROCESS, WHICH IS YET TO BE DEVELOPED, WILL BE AN EXPLOSIVE CONDITIONER

THIS UNIT WILL DO THREE (3) THINGS.

IT WILL REDUCE THE MOISTURE CONTENT TO AN ACCEPTABLE LEVEL, DEAERATE THE EXPLOSIVE AND BRING THE TEMPERATURE OF THE EXPLOSIVE TO THE DESIRED POURING TEMPERATURE

ADDENDUM NO. I

IN A CONVENTIONAL MELT-POUR OPERATION, THE LARGE QUANTITY OF EXPLOSIVE INVOLVED IN THE MELTING PROCESS CONSTITUTES ONLY A PART OF THE TOTAL QUANTITY WHICH IS SUBJECT TO DETONATION BY PROPAGATION.

IF WE ARE TO ATTAIN MAXIMUM PERSONNEL SAFETY AND MINIMUM POTENTIAL PROPERTY DAMAGE, IN THE EVENT OF AN ACCIDENTAL DETONATION IN A MELT-POUR SYSTEM, WE MUST REDUCE THE LARGE CONCENTRATIONS OF EXPLOSIVE AND PERSONNEL EXPOSURE THROUGHOUT THE ENTIRE MELT-POUR PROCESS.

IN ORDER TO ACCOMPLISH THIS, WE MUST HAVE SOME MEANS OF HANDLING THE PROJECTILES THROUGHOUT THE MELT-POUR PROCESS THAT WILL KEEP THE LOADED PROJECTILES SEPARATED NON-PROPAGATING DISTANCE AND WILL ENABLE ALL OPERATIONS TO BE PERFORMED AUTOMATICALLY.

IF WE ARE TO EXPECT CONSISTENT QUALITY IN THE CAST, EACH PROJECTILE OR SHELL BODY MUST BE GIVEN EXACTLY THE SAME TREATMENT. TO DO THIS WE MUST HAVE COMPLETE CONTROL OVER EACH INDIVIDUAL PROJECTILE.

PRESENT "STATE-OF-THE-ART" IN THE MATERIAL HANDLING FIELD, TO MY KNOWLEDGE, DOES NOT OFFER A STANDARD CONVEYOR THAT WILL SATISFY THESE REQUIREMENTS.

REALIZING THE NEED FOR SUCH A CONVEYOR IN THE MODERNIZATION AND AUTOMATION OF OUR MELT-POUR OPERATIONS, WE AT MILAN ARMY AMMUNITION PLANT CAME UP WITH A NEW CONVEYOR CONCEPT WHICH WE FEEL WILL MEET THE REQUIREMENTS OUTLINED.

I WOULD LIKE TO SHOW YOU A FEW SLIDES TO FAMILIARIZE YOU WITH THE BASIC PRINCIPLE AND THEN A SHORT MOVIE OF A TEST LOOP INCORPORATING THE VARIOUS FEATURES AND MOTIONS THAT CAN BE ATTAINED WITH THIS PRINCIPLE.

THE ASESB - WHAT WE ARE DOING AND WHY

Moderator:

C. A. Breeding and N. D. Bachtell
Armed Services Explosives Safety Board
Washington, D. C.

BLANK PAGE

THE ASESB - WHAT WE ARE DOING & WHY

At the outset I would suspect that many of you have little factual information regarding the ASESB operations and worldwide responsibilities. Allow me to briefly orient in order that you may review our efforts in a proper perspective.

By Act of Congress on 29 May 1928 the ASESB was born; it currently functions in accordance with DOD Directive 5154.4, 25 July 1963, issued by the Secretary of Defense. This instrument provides that the ASESB shall advise the Secretary of Defense and the Secretaries of the Military Departments on ammunition and explosives manufacturing, storage, transportation, handling, testing, and siting. We, in brief, are continuously alert to conditions which endanger life and property both within and outside DOD installations. The Board Chairman is selected by the Secretary of Defense. The Board consists of the Chairman and three Members with their designated alternates. These Members, with the exception of the Chairman, serve in this capacity on an additional duty basis; in other words, they have and perform full-time assignments within their respective Military Departments. Aside from the Board, the Chairman in the execution of his duties has a permanent "Secretariat" consisting of 10 safety engineers and one Navy and one Army officer. The Chairman receives policy direction and program guidance from the Assistant Secretary of Defense (I&L) and reports to him.

The responsibilities assigned to the Board, in addition to the one previously mentioned, are:

a. Establish safety standards.

b. Review and evaluate all general site plans for construction or modification of ammunition and explosives facilities and approve or disapprove as appropriate.

c. Survey, study, and evaluate activities to determine compliance with ammunition and explosives safety standards and to detect hazardous conditions.

d. Maintain liaison with other Government Departments, allied governments, and industrial organizations having a mutual interest or responsibility in safety matters involving ammunition and explosives.

e. Review and analyze reports, data and information from all sources, in which ammunition and explosive hazards, accidents, and safety are involved.

f. Conduct investigations, studies, and test programs concerning ammunition and explosives hazards.

g. Perform other duties as may be assigned by the Assistant Secretary of Defense (I&L).

In fulfilling these responsibilities I would like to tell you about some of the things which the Board and Secretariat are doing. As of 1 June of this year Colonel William Cameron III, USAF, became Chairman of the Board. Colonel Cameron's philosophy is team-work. He feels the Board is an organization which must perform a service, not only for the DOD but to assist, also, other Government agencies -- Federal and state -- and private industry as well. We believe that the Board, all the Government components, and industry, having a mutual interest in explosives safety, working together as a team, can meet the challenge to devise ways and means whereby the science of explosives safety will be progressed thus enabling those we continuously seek to serve to reap maximum benefits therefrom.

By way of clarification, but with no intent to belabor, allow me to comment regarding the pulse of the country. In brief, we, together with many others, have become increasingly alert to the deep concern being vocalized in many quarters regarding public exposures, which have increased tremendously over approximately the last ten years, to hazards associated with manufacturing, storage, and transport of explosives and other hazardous materials.

The Board, in the discharge of its responsibility to establish safety standards, achieves these results by a combination of:

a. Review of the results of past accidents.

b. Experimental effort to evaluate specific problems.

c. Analytical and mathematical modeling approach to make use of modern scientific techniques.

To the extent practicable, the research and development effort confirmed with analytical solutions and vice versa so that each technique will give greater confidence in the other. The hoped-for result of this is to reduce the past complete dependence upon data from disastrous explosions which occurred.

A case in point is the review of the quantity-distance tables. Current tables are based in large measure upon past accident experience. In many cases, the very limited amount of statistical data available and its use by different investigators without proper correlation has led to tables which are not adequate for all situations. Changes in building technology and facilities-use also tend to make them out of date.

Modern methods of blast measurement and prediction, structural analysis, and mathematical modeling can and should be used to refine the estimates of expected damage.

A contract sponsored by the Board on the Analysis of Blast Vulnerability of selected targets has been completed. This provides a mathematical model for computer analysis of the behavior of ten selected targets subjected to the pressure and impulse from blasts originating from explosions of several different sizes. This task should also permit evaluation of the validity of the various tables for targets of different character and greater complexity and at various distances from the source explosion.

In addition to the problem of quantity-distance tables per se and new distances which may be required, existing tables give credit for barricading, frequently on the basis that barricaded distances are 1/2 the unbarricaded. This is not based upon any scientific principle but more upon historical accident than anything else. The Board is attempting through research contracts to obtain a mathematical model and suitable hydrodynamic computer code which will allow analysis of the blast wave diffraction around barricades of various types and in various positions. This will permit a determination as to when barricade effects on shock wave intensity should modify the distance tables and when it is inappropriate for them to do so.

Standards governing protection against fragment and debris dispersal are based largely upon a very limited number of tests in past years. They do not adequately take into account the variations of fragment density or range expected from the large variety of ammunition developed since the original standards were adopted. There is no clear way to define hazards from various types of fragment-producing ammunition and from the debris of buildings destroyed by explosions either as to:

Probability of hits
Acceptable probability level
Risk of damage or casualty if a hit occurs

A fragment hazard study is being performed under contract which will provide a mathematical model and computer program for estimating probability of hazardous fragment strikes at various distances outward from an explosion source. The output will be in the form of probability contours which can be used to estimate the hazard to any target at any required distance.

For more details on results of these contracts mentioned, I would recommend you attend Dr. Zaker's session in which such areas as blast effects, effects of barricades on blast, residential damage, fragment hazards, and fire (thermal) hazards will be dealt with.

The Board also makes use of working groups to develop or to revise standards. Currently the Board has 5 active working groups. They are:

DOD Contractors' Safety Manual for Ammunition, Explosives, and Related Dangerous Material

Safety Criteria for Liquid Propellants

Special Instructions for Commanders of Aircraft and Drivers of Motor Vehicles Transporting Explosives and Certain Other Dangerous Articles

Fragment Hazards (advisory function on monitoring contract)

Explosives Hazard Classification Procedures

The review and evaluation of all general site plans for the construction and modification of ammunition and explosives facilities of the DOD components accomplished by the Secretariat. Plans are approved or disapproved as appropriate.

Members of the Secretariat conduct regular and continuous surveys of all Department of Defense installations wherever ammunition and explosives are handled, manufactured, and stored for the purpose of determining compliance with DOD safety standards and to detect hazardous conditions.

In addition to the activities described previously, the Board's Secretariat participates actively in work groups and discussion meetings of other agencies such as NASA, AEC, DOT, National Research Council of the National Academy of Sciences, and various other organization-sponsored activities having a mutual interest in explosives safety. A very close informal relationship exists with the Explosives Storage & Transport Committee, a sort of an analog to the ASESB, in the United Kingdom and regular representation is provided to the NATO Group of Experts on the Safety Aspects of Transportation and Storage of Military Ammunition and Explosives.

Gentlemen, we know over the years you have been informed of tests which have been conducted, those which are in being as well as the many other attributes of the Board. During this session we would like to briefly discuss some of the omissions and conflicts. There are situations for which the U.S. does not have any criteria as well as areas where there is no semblance of agreement between the U.S. provisions and that of other countries throughout the world with which we have dealings. For instance, let's take just a few of the problem areas.

a. Underground storage
b. Compatibility
c. Basic load storage
d. Fire symbols

First, let's take the problem of underground storage. The U.S. does not have any published criteria which personnel in the field can use where storing in these type facilities. The NATO criteria contains a section on underground storage, which was originally based on World War II data. I don't know if you are aware of the fact that the Board represents the U.S. at NATO on the development of the NATO ammunition storage criteria. Norway, who is a member of NATO, stores practically all of their munitions in these type facilities. The NATO criteria, when originally published, differed greatly from that which was being used by Norway at that time. In order to resolve the differences, Norway conducted a series of tests and as a result the NATO criteria was modified. The revised NATO criteria has been submitted to DASA, who has been asked to review in light of DASA tests. DASA comments will be considered by the NATO working group for adoption. The entire underground storage criteria is being considered for incorporation in DOD standards. The U.S. is presently using facilities of this type in Hawaii, Japan, and the United Kingdom. Over the period of years the level protection afforded the areas surrounding these locations has been a matter of concern to everyone. The criteria under consideration takes in account the amount of overburden and whether it is desirous to prevent debris throw. The leg work on this criteria for inclusion as a U.S. standard is moving along and it is anticipated that publication of this criteria should occur with the year.

Compatibility. At the present time there are four different compatibility groupings used in the U.S.

1. Army and Air Force
2. Navy
3. Coast Guard
4. DOT surface

There are some similarities within these groups; however, the differences within the groups are tremendous. In addition to these differences

there is also another problem. The United Nations Organization has adopted a system of compatibility for sea transport; this UN system is being incorporated into the IMCO (Intergovernmental Maritime Consultive Organization) regulations and if a country so adopts this system any material being shipped to them by the U.S. must comply with the UN system. It is understood that 28 countries have indicated acceptions of this system and it will become effective in early 1971. This system of compatibility has also been adopted by NATO for storage purposes. In light of the above, it is necessary that DOD and DOT adopt a uniform system compatible to that of the UN. The UN regulations require that all packages be marked in accordance with the UN compatibility group. Each group within this system is specifically defined as to items which may be stored together.

In addition, the package will also have to show the UN hazard class of the ammunition. To give you some idea of the problems in this field, UN has four classes: 1.1, 1.2, 1.3, 1.4; NATO has six classes: 1 thru 6; US has seven classes: 1 thru 7; UK has five classes: X, Y, Z, ZZ, and Safety.

Although confusion appears to be rampart due to the different number of classes in each system, it really isn't as bad as in other fields. A greater problem exists when converting U.S. military storage classes into either DOT or Coast Guard. There has been some discussion on this subject to the possibility of changing the present number of U.S. storage classes; however, nothing has been done formally to make any changes in the system presently being used by the U.S. There has been considerable discussion by DOT regarding the acception of the UN hazard classification system for all modes of transport. Uniformity must exist due to increased use of intermodal containers. You can easily see the need for work in this area.

Basic load storage. This is primarily an Army problem in Europe. In order for the combat units to meet their commitments, it is necessary that their weapons and ammunition be readily available; consequently tanks, trucks, trailers and other types of combat vehicles loaded with ammunition are parked nearby housing areas, schools, homes of foreign nationals, etc. There has never been any form of guidance available to the personnel responsible for these situations as to the hazard free area that should be maintained around these locations. The Board, along with USAREUR personnel and representatives of the Federal Republic of Germany, developed standards to be used for these situations. This standard is being considered for acceptance by the NATO countries and inclusion in their document and it is presently being considered for inclusion in U.S. standards. We feel that from a safety point of view and taking into consideration the operational requirement, this standard provides a reasonable degree of protection.

Let's take our Classes 3, 4, 5, and 6, in our tables we operate on a fixed distance regardless of the amount. Most other countries vary the distances according to the amount of material in storage, in other words, fragment density is considered the primary factor. Although all of the standards do have a minimum distance, one of these tables uses the formula of one effective fragment per 600 square feet. An effective fragment is considered to have kinetic energy 56 foot pounds or greater at the point of impact. The U.S. does not have such a formula for the establishment of fragment density, and it is one area that definitely needs looking into. At the present time, we are investigating the use of a similar procedure to determine the level of risk for small quantities cased Class 7 items. The criteria being considered involves the probability of a damaging fragment striking a given target. The probabilities are in the range from 1 in 10 to 1 in 100. It is anticipated that a minimum distance will be established for cased Class 7 munitions to give protection against fragments.

Let's look at our present regulations' inconsistencies. Take for example the 2.75" rocket, if this item is assembled with an inert head it is considered by one service as a Class 5 item requiring 1200 feet to an inhabited building; however, if we assemble an H.E. head in this item, it then becomes Class 7. Now, let's take an actual case. The storage location was approximately 700 feet unbarricaded from an inhabited building. Now, according to the present regulations, you legally could not store one round of the inert 2.75" rocket but could store up to 600 lbs. of HE if the rockets were assembled with an HE head. Many similar situations exist in our present day standards.

Another area of concern is the establishment of uniform fire symbols with the DOD. At the present time, the Army/Air Force have one system while the Navy has a completely different system. The Army/Air Force use a system of numbers 1 thru 4 with 1 being the least hazardous and 4 indicating the most hazardous material. This system although it has been in use many years does not truly reflect the basic hazard involved. Normally, minor hazard, fire, fragmentation, and blast. As you know, symbol 4 indicated Classes 4 thru 7; consequently you can not determine whether the structure contains fragment-producing items or mass detonating items. The system used by the Navy consists of a color code system permanently painted in the structure. This system depicts the hazard but has many disadvantages. Efforts should be made to establish a uniform system within DOD and then attempt to establish a uniform world wide system, so that regardless of what country our personnel are assigned that the hazard would be readily recognized and understood by both US and host nation personnel. U.K. system is similar to NATO where a #1 symbol represents the most hazardous.

It would appear that on the surface that to change a regulation would be relatively easy. Let's suppose that a change has been recommended to the Services for consideration. Here are some of the implications:

a. All of the reference directives, publications, etc., of each Service must be changed.

b. The man hours and cost involved.

c. The impact on application of the change:

(1) How it is to be applied.
(2) How it effects mission capability.
(3) Costs involved in possible restorage, relocation, or new construction.
(4) Other hidden costs.

(a) Studies
(b) Issuance of waivers to cover temporary situations
(c) Correspondence

In addition to the above, some of the other problems in modifying or changing a regulation are that the Board can only recommend and that the Services have to concur before publication. Usually, the individuals of each Service that concur in these changes are the ones responsible within their Service for assuring compliance. Therefore, you can easily understand why the Services are reluctant to agree on changing a regulation which would create additional problems.

ATTENDEES

ADAMS, G. E.	Honeywell Inc., Minneapolis, Minn.
ALLAN, D. S.	Arthur D. Little, Inc., Cambridge, Mass.
AMMERMAN, D. J.	Naval Weapons Laboratory, Dahlgren, Va.
ARMBRUST, E. F.	Sandia Laboratories, Albuquerque, N. M.
ASBURY, R. L.	Hercules Incorporated, Radford, Va.
ASHCRAFT, F. M.	Military Airlift Command, Scott AFB, Ill.
ASHLEY, M. M.	Eglin AFB, Fla.
AUL, E. T.	Seneca Army Depot, Romulus, N. Y.
AUVENSHINE, B. F.	Atlantic Research Corp., Costa Mesa, Cal.
BACHTELL, N. D.	Armed Services Explosives Safety Board
BAILEY, M. R.	USAMC Field Safety Agency, Charlestown, Ind.
BALDONADO, O. C.	Holmes & Narver, Inc., Los Angeles, Cal.
BALDWIN, W. J.	Defense Supply Agency, Alexandria, Va.
BARAN, C.	Hq 21st Air Force, McGuire AFB, N. J.
BARBAREK, L. A. C.	IIT Research Institute, Chicago, Ill.
BARON, J. H.	Naval Ordnance Systems Command, Wash, DC
BEDELL, W. A.	Bendix Launch Support Div., Merritt Is., Fla.
BEDENBAUGH, B. A.	North American Rockwell Corp., McGregor, Tex.
BELLIVEAU, L. J.	Defense Atomic Support Agency, Wash, DC
BERGAN, J. D.	USA Pacific, APO San Francisco 96558
BIRETTA, COL A. A.	Dir of Aerospace Safety, Norton AFB, Cal.
BLANKENBECLER, COL R. M.	Hq Strategic Air Command, Offutt AFB, Neb.
BOBKO, J. R.	AFPRO, Lockheed Msls & Space Co., Sunnyvale, Cal.

BORUM, O. H.	Army Materiel Command, Wash, DC
BORGSTROM, LTC T. J.	SAMTEC, Vandenberg AFB, Cal.
BOYD, G. F.	Tri-State Motor Transit Co., Joplin, Mo.
BRAMEIER, H. A.	Aberdeen Proving Ground, Md.
BRANDAU, Frank	Austin Powder Co., McArthur, Ohio
BRASWELL, A. T.	Red River Army Depot, Texarkana, Tex.
BREEDING, C. A.	Armed Services Explosives Safety Board
BRETTEL, E. G.	Day & Zimmermann, Inc., Parsons, Kansas
BROBST, W. A.	Department of Transportation, Wash, DC
BROWN, S. F.	Milan Army Ammunition Plant, Tenn.
BURCH, C. A.	AEC, Albuquerque Operations Office, N. M.
BUSBY, MAJ A. E.	1002nd IG Group, Norton AFB, Cal.
BUSCHMAN, E. H.	Naval Ammunition Depot, Crane, Ind.
BUTAS, J. A.	USA Safeguard Systems Command, Huntsville, Ala.
CAIN, G. E.	Hercules Incorporated, Wilmington, Del.
CALL, R. J.	Olin Corporation, Marion, Ill.
CAMERON, COL WM III	Chairman, Armed Services Explosives Safety Board
CAMPBELL, C. D.	USA Foreign Science & Technology Ctr, Charlottesville, Va.
CAMPBELL, C. J.	USA Weapons Command, Rock Is., Ill.
CARMICHAEL, CAPT R. W.	Hq Tactical Air Command, Langley AFB, Va.
CARNEY, R. E.	Hq Military Airlift Command, Scott AFB, Ill.
CASSLER, E. B.	Hercules Incorporated, Magna, Utah
CHAR, W. T.	USA Corps of Engineers, Huntsville, Ala.
CHILDRESS, W. L.	Thiokol Chemical Corp., Brigham City, Utah

CHRISTOFANO, E. E.	Hercules Incorporated, Wilmington, Del.
CHURCHILL, W. D.	USA Corps of Engineers, Mo. River Div., Omaha, Neb.
CLARK, MAJ E. M.	Hq USAFE IG, APO New York 09633
CLAXTON, R. D.	AFPRO, Ogden, Hill AFB, Utah
CLAYTON, W. N.	Badger Army Ammunition Plant, Baraboo, Wisc.
CODER, LTC J. D.	Armed Services Explosives Safety Board
COLBATH, L. E.	Tooele Army Depot, Utah
COLE, L. F.	AMC Installations & Services Agency, Rock Island, Ill.
COLLINS, W. B.	Hq ADTC, Eglin AFB, Fla.
COMINS, T. E.	OOAMA (MMNTR), Hill AFB, Utah
CONLEY, J. H.	Aberdeen Proving Ground, Md.
CORLETT, L. H.	Naval Weapons Center, China Lake, Cal.
COX, Z. J.	Deseret Test Center, Fort Douglas, Utah
COURTRIGHT, W. C.	UnivCal, Los Alamos Scientific Lab, N.M.
COWAN, G. H.	USA Munitions Command, Picatinny Arsenal, N.J.
COYLE, C. R.	Naval Ordnance Systems Command, Crane, Ind.
CROOK, A. M.	Indiana Army Ammunition Plant, Charlestown, Ind.
CULLY, T. S.	AVCO Precision Products Div., Richmond, Ind.
CUNNIFF, R. E.	Uniroyal Inc., Joliet, Ill.
CUNNINGHAM, LCDR J. F.	Pacific Missile Range, Point Mugu, Calif.
CUSTIS, I. H.	Naval Air Development Center, Warminster, Pa.
CUTSINGER, J. E.	USA Missile Command, Redstone Arsenal, Ala.
DACHILSEN, Peter	Picatinny Arsenal, Dover, N. J.
DALE, C. B.	Naval Ordnance Station, Indian Head, Md.

DAUGHERTY, E. A.	Naval Air Systems Command, Wash, DC
DEANS, H. L.	USA Materiel Command, Wash, DC
DEL REGNO, L.	DCASR, Dallas, Texas
DE ROSE, C. E.	NASA, Ames Research Center, Cal.
DI GRAZIA, H. X.	Lawrence Radiation Lab., Livermore, Cal.
DOBBS, N. G.	Ammann & Whitney, New York, N. Y.
DORAN, J. W.	Engineering Res Lab, Aberdeen Proving Ground, Md.
DORTON, J. R.	Lexington-Blue Grass Army Depot, Ky.
DOUGLAS, J. E.	Lake City Army Ammunition Plant, Independence, Mo.
DOUGLAS, R. L.	USA Continental Army Command, Fort Monroe, Va.
DOWLING, T. P.	Trojan-U.S. Powder, Allentown, Pa.
DRISCOLL, T. W.	DCASR, Atlanta, Ga.
DUNN, M. L.	Armed Services Explosives Safety Board
DUNWOODY, Cecil	62nd Mil Alft Wg, McChord AFB, Wash.
DYER, H. C.	NASA, Marshall Space Flight Center, Huntsville, Ala.
EAVENSON, T. J.	Directorate of Aerospace Safety, Norton AFB, Cal.
EDWARDS, J. O.	Martin-Marietta Corp., Vandenberg AFB, Cal.
EHRENKRANZ, T. E.	UnivCal, Los Alamos Scientific Lab., N.M.
EHRINGER, A. G.	Savanna Army Depot, Ill.
ELSASSER, F. M.	60 Mil Alft Wg, Travis AFB, Cal.
EUBANK, R. L.	Red River Army Depot, Texarkana, Texas
EWING, L. C.	Atlas Chemical Industries, Inc., Chattanooga, Tenn.
FABIAN, J. S.	NASA, JFK Space Center, Fla.
FAIRCHILD, J. M.	AFPRO, Aerojet-General Corp., Sacramento, Cal.

FALVO, M. J.	NASA, Manned Spacecraft Ctr, Houston, Tex.
FARBER, E. A.	UnivFlorida, Gainesville, Fla.
FARMER, A. A.	Polaris Missile Facy Pacific, Bremerton, Wash.
FARMER, M. D.	Lexington-Blue Grass Army Depot, Ky.
FEINGLAS, J. M.	436th MilAirlft Wg, Dover AFB, Del.
FEINSTEIN, David	IIT Research Institute, Chicago, Ill.
FIDELL, F. J.	Frankford Arsenal, Philadelphia, Pa.
FINE, W. T.	Naval Ordnance Laboratory, Silver Spring, Md.
FINKEL, M. G.	Sierra Army Depot, Herlong, Cal.
FIRENZE, R. J.	Naval Ammunition Depot, Crane, Ind.
FITZGERALD, J. A.	Honeywell Inc., New Brighton, Minn.
FORSTEN, I.	Picatinny Arsenal, Dover, N. J.
FORSYTHE, F. J.	Joliet Army Ammunition Plant, Ill.
FOSMIRE, D. F.	ADWC, Tyndall AFB, Fla.
FRAZIER, J. D.	McDonnell Aircraft Co., St. Louis, Mo.
FUNSTON, LCDR W. H.	Naval EOD Facility, Indian Head, Md.
GANS, CDR G. M.	Naval Ordnance Systems Command, Wash, DC
GARVEY, LCDR D. P.	Naval Safety Center, Norfolk, Va.
GEKLER, W. C.	Holmes & Narver, Inc., Los Angeles, Cal.
GELTZ, W. H.	Naval Weapons Station, Concord, Cal.
GENIUSZ, S. T.	AFLC, Wright-Patterson AFB, Ohio
GERA, John	North American Rockwell Corp., Downey, Cal.
GERARD, J. A.	DCASR, Boston, Mass.
GILMORE, A. E.	Naval Ammunition Depot, Crane, Ind.
GLENZER, W. K.	Naval Ammunition Depot, Hawthorne, Nevada

GOFF, C. R.	Day & Zimmermann, Inc., Texarkana, Tex.
GOOCH, T. R.	Thiokol Chemical Corp., Huntsville, Ala.
GOODPASTURE, R. E.	Naval Ammunition Depot, Crane, Ind.
GOTT, R. W.	Hercules Incorporated, Wilmington, Del.
GRAVES, B. B.	AFRPL, Edwards, Cal.
GREGG, MAJ J. L.	Office of the Surgeon General, DA, Wash, DC
GRIFFIN, E. N.	Hercules Incorporated, Cumberland, Md.
GRIFFIN, LTC P. A.	Ravenna Arsenal, Ravenna, Ohio
GRIMALDI, J. V.	Center for Safety, New York, N. Y.
GROVES, W. E.	DCASR, Detroit, Mich.
GRYTING, H. J.	Naval Weapons Center, China Lake, Cal.
GUNN, CDR M. C.	Naval Safety Center, Norfolk, Va.
HALL, P. H.	Hq Military Airlift Command, Charleston AFB, S.C.
HALLSTEAD, J. W.	Naval Ordnance Systems Command, Wash, DC
HAMILTON, Norl	Atlas Chemical Industries, Inc., Chattanooga, Tenn.
HAMMON, S. O.	Vibration Damage Specialists, Louisville, Ky.
HANEY, C. J.	Defense Atomic Support Agency, Wash, DC
HANNA, R. B.	Naval Ammunition Depot, Forrest Park, Ill.
HANNA, R. J.	Boeing Company, Seattle, Wash.
HANNAH, M. M.	Hq 63rd Mil Alft Wg, Norton AFB, Cal.
HARKER, N. C.	AEC, Albuquerque Operations Office, N. M.
HARPER, B. R.	Pace Corporation, Memphis, Tenn.
HARTMAN, F. X.	NASA, JFK Space Center, Florida
HARTON, E. E.	Department of Transportation, Wash, DC
HAYDEN, W. G.	Olin Corporation, East Alton, Ill.

HEAD, E. L.	Remington Arms Co., Lonoke, Ark.
HELLE, C. J.	Companhia Brasileira de Cartuchos, Remington Arms Co., Sao Paulo, Brazil
HENDERSON, W. P.	Edgewood Arsenal, Md.
HENNARD, H. S.	Uniroyal Inc., Joliet, Ill.
HERMAN, Robert C.	Armed Services Explosives Safety Board
HESS, Frederick	Priority Air Dispatch Inc., Wash, DC
HESS, Victor	Priority Air Dispatch Inc., Wash, DC
HEWES, W. J.	Atlantic Research Corp., Gainesville, Va.
HILL, T. P.	Day & Zimmermann, Inc., Philadelphia, Pa.
HILL, W. L.	Black & Veatch, Kansas City, Mo.
HILLYER, LTC W. K.	Hq USAF (IGDA), Wash, DC
HINDLE, R. R.	NASA, Wallops Station, Wallops Is, Va.
HINSON, P. C.	Mason & Hanger-Silas Mason Co., Inc., Burlington, Iowa
HOLMAN, H. K.	Transportation Engineering Agency, Ft. Eustis, Va.
HUDGINS, M. M.	USA Missile Command, Redstone Arsenal, Ala.
IRWIN, B. F.	Alaskan Air Command, APO Seattle, Wash.
JACKSON, E. V.	Mason & Hanger-Silas Mason Co., Lexington, Ky.
JENSEN, Omar B.	USA Ammo Proc & Supply Agency, Joliet, Ill.
JEWETT, R. E.	Military Ocean Terminal, Sunny Point, N. C.
JEZEK, Louis	USA Materiel Command, Wash, DC
JOHNSON, L. J.	NASA, Langley Research Center, Hampton, Va.
JOHNSON, R. E.	Olin Corporation, Badger A.P, Baraboo, Wisc.
JOHNSON, R. K.	North American Rockwell Corp., Downey, Cal.

JONES, F. M.	Aerojet Solid Propulsion Co., Sacramento, Cal.
JONES, SMSGT G. J.	TSWC/EOD, Lowry AFB, Col.
JONES, W. P.	Yuma Proving Ground, Arizona
JORDAN, R. A.	Hercules Incorporated, Sunflower AAP, Kan.
KEEFER, J. H.	Ballistic Research Labs., Aberdeen PG, Md.
KELLY, J. P. H.	AEC, Division of Operational Safety, Wash, DC
KERVIN, T. L.	White Sands Missile Range, Las Cruces, N. M.
KIEKE, Romie H.	Armed Services Explosives Safety Board
KING, P. V.	General Electric Co., Bay St. Louis, Miss.
KINGERY, C. N.	Ballistic Research Labs, Aberdeen PG, Md.
KINNEY, R. B.	ADC (DMME), Ent AFB, Col.
KITTS, K. A.	Naval Weapons Laboratory, Dahlgren, Va.
KNOTT, E. F.	Naval Ord Test Unit, Patrick AFB, Fla.
KOGER, D. M.	General Electric Co., Bay St. Louis, Miss.
KOMOS, J. N.	DCASR, St. Louis, Mo.
KORMAN, Philip	Picatinny Arsenal, Dover, N. J.
KRIKORIAN, M.	Brunswick Corp., Chicago, Ill.
KRISTOFF, F. T.	Hercules Incorporated, Radford, Va.
KUHN, R. R.	Aberdeen R&D Center, Aberdeen PG, Md.
KYRKJEBO, MAJ GUNNAR	Ministry of Defense, Oslo, Norway
LANGSDALE, CAPT R. E.	AFWL, Kirtland AFB, N. M.
LAVIN, CDR C. V.	Armed Services Explosives Safety Board
LAWLER, MAJ F. C.	USA Combat Developments Command, Ft Belvoir, Va.
LAWRENCE, P. A.	Natl Air Pollution Control Admin, HEW, Rockville, Md.

LEAPE, C. V.	Naval Ord Systems Support Office Pacific, San Diego, Cal.
LEIGH, C. S.	Northrop Carolina Inc., Asheville, N. C.
LEONARDI, R. G.	Picatinny Arsenal, Dover, N. J.
LESLIE, E. B.	Anniston Army Depot, Anniston, Ala.
LEVENS, Ernest	McDonnell Douglas Corp., Santa Monica, Cal.
LEWIS, H.	du Pont de Nemours & Co., Carney's Pt, N.J.
LITTLEFIELD, MAJ D. W.	Hq US Air Force Europe, APO New York
LOGAN, J. E.	Western Electric Co., Greensboro, N. C.
LOWELL, John W.	Armed Services Explosives Safety Board
McCARLEY, WO CW2 T. K.	Naval EOD Facility, Indian Head, Md.
McDOWALL, M. D.	Canadian Department of National Defence, Ottawa, Canada
McGOWAN, J. R.	McDonnell Douglas Astronautics Co., Titusville, Fla.
McKAY, R. M.	USA Materiel Command, Wash, DC
McQUISTION, W. E.	Naval Ordnance Station, Indian Head, Md.
McSMITH, Duane	NASA, Langley Research Center, Hampton, Va.
MAAS, A. V.	Naval Ordnance Systems Command, Wash, DC
MAGUIRE, R. I.	AFRPL, Edwards AFB, Cal.
MANN, B. C.	Air Force Systems Command, Andrews AFB, Wash, DC
MARSISCHKY, G. W.	Naval Ammunition Depot, Crane, Indiana
MATHIS, J. M.	Martin Marietta Corp., Vandenberg AFB, Cal.
MAXWELL, L. V.	Naval Ammunition Depot, McAlester, Okla.
MAYOR, A. J.	Sea-Land Service, Inc., Wash, DC
METCALF, Howard	Office, Asst. Secretary of Defense (I&L), Wash, DC

MILLER, C. G.	du Pont de Nemours & Co., Martinsburg, W.Va.
MILNER, J. R.	Holston Defense Corp., Kingsport, Tenn.
MISENER, C. C.	Naval Ordnance Laboratory, Silver Spring, Md.
MOLLOY, J. J.	North American Rockwell, El Segundo, Cal.
MOORE, C. J.	Naval Ammunition Depot, Hawthorne, Nevada
MORE, W. M.	438 MAWG, McGuire AFB, N. J.
MORGAN, A. J.	AF Flight Test Center, Edwards AFB, Cal.
MORRIS, C. S.	Tooele Army Depot, Tooele, Utah
MULAC, Lawrence	Badger Army Ammunition Plant, Baraboo, Wisc.
MURPHY, J. L.	Thiokol Chemical Corp., Huntsville, Ala.
MYERS, R. L.	USA Materiel Command Fld Safety Agency, Charlestown, Ind.
NAPADENSKY, MRS. HYLA S.	IIT Research Institute, Chicago, Ill.
NEWMAN, C. E.	Umatilla Army Depot, Hermiston, Oregon
NIEMITZ, J. J.	Naval Ammunition Depot, Oahu, Hawaii
NOLAN, W. J.	USA Munitions Command, Dover, N. J.
NOSER, W. F.	Office, Chief of Engineers, Wash, DC
O'DRISCOLL, J. J.	Southern Railway System, Atlanta, Ga.
O'GRADY, F. P.	Directorate of Aerospace Safety, Norton AFB, Cal.
O'MALLEY, C. A.	TRW Systems Group, San Bernardino, Cal.
OVERBEY, C. A.	NASA, JFK Space Center, Fla.
PADILLA, E. F.	White Sands Missile Range, Las Cruces, N. M.
PANKOW, J. F.	General Electric Co., Bay St. Louis, Miss.
PARKER, G. W.	Military Ocean Terminal, Sunny Point, N. C.

PARKS, D. K.	Falcon R&D Co., Denver, Col.
PELL, H. D.	Custom Materials, Inc., Chelmsford, Mass.
PERKINS, R. G.	Armed Services Explosives Safety Board
PETES, Jos.	Naval Ordnance Laboratory, Silver Spring, Md.
PETRICK, J. T.	Naval Weapons Laboratory, Dahlgren, Va.
PETRIE, J. W.	Directorate of Safety, Hq USAF Europe
PHILLIPS, D. E.	Naval Ordnance Laboratory, Silver Spring, Md.
PHILLIPS, Herman	Mason & Hanger-Silas Mason Co., Inc., Amarillo, Texas
PLATE, S. W.	Tri-State Motor Transit Co., Arlington, Va.
POLSON, J. R.	Mason & Hanger-Silas Mason Co., Inc., Burlington, Iowa
PRIOR, L. C.	Jet Propulsion Laboratory, Pasadena, Cal.
RACHEL, C. K.	Hughes Aircraft Co., Tucson, Ariz.
RAFAEL, H. J.	ADC, Ent AFB, Col.
RAIFORD, J. P.	Strategic Air Command, Offutt AFB, Neb.
REEL, L. R.	KDI Precision Products, Inc., Cincinnati, O.
REEVES, H. J.	Ballistic Research Labs., Aberdeen PG, Md.
REHMANN, W. H.	General Electric Co., Bay St. Louis, Miss.
REMPFER, E. J.	Frankford Arsenal, Phila., Pa.
RHOADS, D. E.	du Pont de Nemours & Co., Newport AAP, Ind.
RHODES, D. B.	Lone Star Army Ammo Plant, Texarkana, Texas
RICHARDSON, J. M.	Sperry Rand, Louisiana AAP, Shreveport, La.
RICHARDSON, R. H.	Hercules Incorporated, Allegany Ballistic Lab, Cumberland, Md.
RICHMOND, D. R.	Lovelace Foundation, Albuquerque, N. M.

RINDNER, R. M.	Picatinny Arsenal, Dover, N. J.
ROBBINS, R. G.	USA Air Defense Command, Ent AFB, Col.
ROBERTS, L. L.	NASA, Marshall Space Flight Ctr, Huntsville, Ala.
ROESCH, D. A.	McDonnell-Douglas Astronautics Co., Cocoa Beach, Fla.
ROSER, E. G.	ADTC, Eglin AFB, Fla.
ROSSER, T. B.	USA Engineers Waterways Experiment Station, Vicksburg, Miss.
ROURE, J. J.	Direction Des Poudres, Paris, France
ROYLANCE, H. M.	Naval Ordnance Systems Command, Wash, DC
ROZAS, C. J.	North American Rockwell, Canoga Park, Cal.
SADWIN, L. D.	Naval Ordnance Laboratory, Silver Spring, Md.
SAHLIN, R. A.	Remington Arms Co., Bridgeport, Conn.
SAMPSON, J. R.	USA Weapons Command, Rock Island, Ill.
SAMS, J. J.	Bendix Launch Support Div., Cocoa, Fla.
SANCHEZ, F. B.	Naval Weapons Laboratory, Dahlgren, Va.
SANSON, J. H.	DCASR, Long Beach, Calif.
SAVAGE, E. G.	McDonnell Douglas Astronautics Co., St. Louis, Mo.
SAVAIKO, B. M.	USA Electronics Command, Fort Monmouth, N. J.
SCARFF, O. W.	USA Aberdeen R&D Center, Aberdeen PG, Md.
SCHIMMEL, B. H.	Pace Corporation, Memphis, Tenn.
SCOTT, H. T.	Atlantic Research Corp., Alexandria, Va.
SCOTT, R. A.	Armed Services Explosives Safety Board
SEAVERS, R. H.	USA Missile Command, Redstone Arsenal, Ala.
SETTLES, J. A.	Hercules Incorporated, Radford AAP, Va.
SEWARD, M. E.	Bell Telephone Labs, Inc., Whippany, N. J.

SHANNON, B. H.	Military Airlift Command, Scott AFB, Ill.
SHOPHER, K. R.	AFLC, Wright-Patterson AFB, Ohio
SHRIVER, R. A.	Military Transportation & Terminal Svc, Wash, DC
SIMON, A. I.	Custom Materials, Inc., Chelmsford, Mass.
SIRIANNE, R. A.	Deputy Chief of Staff for Logistics, DA, Wash, DC
SIRLS, J. M.	Harvey Aluminum Sales, Inc., Milan, Tenn.
SKAAR, K. S.	Naval Weapons Center, China Lake, Cal.
SKELTON, D. J.	USA Nuclear Weapons Surety Group, Ft Belvoir, Va.
SLIGHT, G. E.	Naval Ammunition Depot, Crane, Ind.
SLIWA, A. F.	Naval Ordnance Systems Command, Wash, DC
SMITH, J. B.	NASA, JFK Space Center, Fla.
SMITH, P. J.	Naval Ammunition Depot, Crane, Ind.
SPENCER, N. C.	Pan American World Airways, Inc., Patrick AFB, Fla.
STANCKIEWITZ, W. P.	USA Ammo Procurement & Supply Agency, Joliet, Ill.
STARK, C. G.	Hq Command, USAF, Bolling AFB, Wash, DC
STEVENS, C. J.	Naval Facilities Engineering Command, Wash, DC
STIMMELL, L.	Deputy Chief of Staff for Logistics, DA, Wash, DC
STOFFERS, F. W.	Jet Propulsion Laboratory, Pasadena, Cal.
STONE, W. T.	General Electric, Bay St. Louis, Miss.
STONEBRAKER, H. J.	Tooele Army Depot, Tooele, Utah
STOUT, B. C.	Holloman AFB, N. M.
STRATTON, F. V.	Louisiana Army Ammo Plant, Shreveport, La.
SULLIVAN, T. J.	Naval Ordnance Station, Indian Head, Md.
TAKATA, A. N.	IIT Research Institute, Chicago, Ill.
TEEL, G. D.	Ballistic Research Labs, Aberdeen PG, Md.

TEETER, B. L.	USA Missile Command, Redstone Arsenal, Ala.
THOMAS, E. R.	USA Engineer Div, Huntsville, Ala.
THOMAS, Emil	Wright-Patterson AFB, Ohio
THOMPSON, M. S.	AFETR, Patrick AFB, Fla.
THORNE, E.	Pan American World Airways, Patrick AFB, Fla.
THORPE, H. L.	Northrop Carolina Inc., Asheville, N. C.
TOLINS, A. D.	Naval Facilities Engineering Command, Wash, DC
TOWNSEND, J. E.	Naval Weapons Laboratory, Dahlgren, Va.
UNANGST, R. C.	Savanna Army Depot, Savanna, Ill.
VANN, J. L.	Harvey Aluminum Sales Inc., Milan AAP, Tenn.
VAN PATTEN, E. W.	USA Munitions Command, Picatinny Arsenal, N. J.
VESSELS, C. C.	USA Safeguard System Command, Huntsville, Ala.
VICKERY, J. F.	Embassy of Australia, Washington, D. C.
VOEGLEIN, J. F.	Edgewood Arsenal, Md.
VOGT, C. I.	Naval Ordnance Station, Indian Head, Md.
WALL, L. C.	Picatinny Arsenal, Dover, N. J.
WALL, M.	Thiokol Chemical Corp., Marshall, Texas
WAMPLER, H. W.	US Air Force Europe, APO New York
WATKINS, C. R.	Hq US Air Force, Wash, DC
WEBB, A. J.	Boeing Company, Seattle, Wash.
WEHMHOENER, E. A.	Remington Arms Co., Independence, Mo.
WEINGARTEN, Garry	Picatinny Arsenal, Dover, N. J.
WELLER, J. F.	Naval Ammunition Depot, Crane, Ind.

WEST, F. L.	ADTC, Eglin AFB, Fla.
WHEELER, R. W.	Explosive Technology, Fairfield, Cal.
WHITTEMORE, COL K. S.	Deputy Chief of Staff for Logistics, DA, Wash, DC
WIEDERMANN, A.	IIT Research Institute, Chicago, Ill.
WIGGER, G. F.	Office, Chief of Engineers, DA, Wash, DC
WILLIAMS, J. L.	Holston Defense Corp., Kingsport, Tenn.
WILTON, C.	URS Research Co., San Francisco, Cal.
WINER, Herbert	USA Air Defense Command, Ent AFB, Col.
WIRUTH, A. D.	Naval Weapons Center, China Lake, Cal.
WOOD, T. W.	Jet Propulsion Laboratory, Edwards AFB, Cal.
WOODS, R. E.	NASA, JFK Space Center, Fla.
YOUNG, R. E.	Picatinny Arsenal, Dover, N. J.
ZAKER, T. A.	Armed Services Explosives Safety Board
ZEILER, A.	NASA, JFK Space Center, Fla.
ZELIMER, E. E.	Boeing Company, Hill AFB, Utah